


SM CRSP FINAL REPORT

2002 – 2008

BUILDING HUMAN AND INSTITUTIONAL CAPACITY TO COMBAT
LAND DEGRADATION, POVERTY AND HUNGER




Soil Management CRSP

USAID
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BUILDING HUMAN AND INSTITUTIONAL CAPACITY TO COMBAT
LAND DEGRADATION, POVERTY AND HUNGER

CORNELL UNIVERSITY
MONTANA STATE UNIVERSITY
NORTH CAROLINA STATE UNIVERSITY
UNIVERSITY OF FLORIDA
UNIVERSITY OF HAWAII

Soil Management Collaborative Research Support Program
College of Tropical Agriculture and Human Resources
Department of Tropical Plant and Soil Sciences
1955 East West Road, Agricultural Science Building 205
Honolulu, Hawaii 96822, USA

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Cover photo credits:

top left Stone barriers and land preparation on contours are used to minimize erosion in Siembra, Honduras (*Photo: Marco Trejo, CIAT-MIS*)

top right SM CRSP alumnus, Dr. Mamadou Doumbia (far left), shares ACN technology with farming families in Fansiakoro, Mali (*Photo: Richard Kablan, UH*)

middle right Farm produce sold by women and children at Comoros market in Dili, Timor-Leste (*Photo: Gordon Tsuji, UH*)

bottom right Seedbed with rice to produce seedlings for transplanting following ICM practice in Maliana, Timor-Leste (*Photo: Richard Ogoshi, UH*)

bottom left Dr. Julie Lauren (far left), Cornell PI, listens to Anwara as she describes her success with the healthy seedling technology in Rangpur, Bangladesh (*Photo: Craig Meisner, CIMMYT/Cornell*)

middle left Irrigation practices for home gardens in Huambo, Angola (*Photo: Russell Yost, UH*)

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Acknowledgments

The Soil Management CRSP was established under Title XII of the United States Foreign Assistance Act by the U.S. Agency for International Development in 1981 with North Carolina State University serving as the Management Entity institution until 1996. A process to restructure the Soil Management CRSP by USAID started in late 1995 and resulted in a re-organized program with new participating universities with focus on integrated nutrient management. The process was completed with the election of the University of Hawaii as the Management Entity in 1996. The re-structured Soil Management CRSP was officially established on February 11, 1997 with execution of the Grant document by both the University of Hawaii and the U.S. Agency for International Development.

Over the course of a decade, the successes achieved by the Soil Management CRSP were made possible by an array of individuals, institutions and organizations from collaborating host countries and the U.S. They are identified in the respective chapters of this report. We wish to recognize each of them for their outstanding contributions.

Technical and administrative oversight provided by members of the Technical Committee, the Board of Directors and the External Evaluation Panel are especially appreciated by the Management Entity and each of the Principal Investigators for their time and service to this CRSP and to the science of agricultural systems.

There were three individuals from USAID/EGAT who served as Cognizant Technical Officers for the Soil Management CRSP. We acknowledge the excellent support and service of Charles Sloger, EGAT/AGR (retired), Mike McGahuey, Jr., EGAT/NRM and Adam Reinhart, EGAT/AGR.

Finally, the technical leadership and support of each of the principal investigators are gratefully acknowledged. Their exceptional performance in the conduct of their respective research programs is commended. Their active participation and cooperation in managing their fiscal and human resources resulted in responsible and accountable outcomes on both the technical and financial fronts of this Grant.

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Editors: Gordon Y. Tsuji and Sharon Balas
Design and Production: Sharon Balas

Table of Contents

Executive Summary

The global plan of the Soil Management Collaborative Research Support Program was directed toward attaining a goal of 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.

To achieve this goal, the purpose of the Soil Management Collaborative Research Support Program was to enable its customers make soil management decisions that are at once economically and environmentally safe and to contribute to the on-going international effort to reduce food insecurity by focusing on the following objectives:

► Enable developing country institutions to apply information technology and knowledge-based tools to increase agricultural productivity.
► Enable developing country institutions to scale-up technology adoption by farmers from local to regional scales.
► Strengthen human and institutional capacity to combat poverty, land degradation and food insecurity.

This purpose was attained by replacing trial-and-error decision making with science-based methods that predict outcomes before decisions are made.

Science-based predictions are the main products of collaborative research. There are three purposes for doing research, the first of which is to understand natural processes. Since much is already known about natural processes, the CRSP concentrates on the second and third purposes of research which include using our understanding of processes to make predictions and, ultimately to enable others to use science-based predictions to manage and control outcomes.

Chapters 1 and 2 of this report describe a decision support tool called NuMaSS that enables users to make better fertilizer use decisions. NuMaSS can make a difference on a global scale because improper use of fertilizer is a major cause of low crop yields in developing countries and environmental pollution in industrialized nations. Fertilizer use involves making decisions about adding proper amounts on a timely basis of three nutrient elements including nitrogen, phosphorus and potassium. Adding too much is wasteful and too little defeats the purpose of using fertilizers. NuMaSS contains globally applicable rules which when combined with site-specific, local information, is able to generate answers to "what if" questions related to fertilizer use asked by its users. NuMaSS, like other CRSP decisions support tools, is designed to operate globally on a site-specific basis.

Agricultural land use often affects environments far beyond farm boundaries bringing into conflict economic goals of farmers with quality of life expectations of non-farming communities. In Chapter 3, the advantages of using decision support tools are extended to policy making. At this level the number of stakeholders is large and a participatory approach is taken to satisfy all parties in an equitable manner. This policy decision support approach referred to as "Tradeoff Analysis," like NuMaSS, is globally applicable and relies on site-specific data to generate locally relevant information to support policy making. This tool enables stakeholders to participate in natural resource management and at the same time support farm productivity and competitiveness.

Chapter 4 describes efforts to revitalize agriculture in one of the world's largest food production systems, the rice-wheat cropping system of the Indo Gangetic Plain. Crop yields in this region representing one of the great success stories of the green revolution have stagnated and show signs of declining. The three research purposes of understanding, prediction and control are applied to revitalized farming in this region. A collaborative, participatory approach that is guided by customer priorities has accelerated adoption of new products and practices by groups with diverse objectives and priorities.

Reversing land degradation and global warming by sequestering carbon in soils are the topics covered in Chapters 5, 6 and 7.

Soil carbon sequestration is considered by many to be a WIN-WIN situation as it not only restores ecosystem services and enables a productive and stable farming system to exist, but has the potential to make a significant dent in the rise in greenhouse gases that now threatens our climate. In addition to understanding, predicting and controlling carbon content in soils, a soil carbon accounting and management system for emissions trading has been developed. This system was developed to enable farmers to receive credit for the carbon they have sequestered in their land and paid in cash for an equivalent quantity of carbon dioxide released into the atmosphere by polluting industries. If implemented, carbon trading could become a strong incentive for farmers to adopt practices that increase soil organic matter in their lands.

Biotechnology is a new and expanding field in agriculture. Much is still to be learned, and understanding research predominates over prediction and control research. By engineering genes to control pests that attack the above ground parts of plants, do we impact negatively on beneficial organisms that maintain symbiotic relationships in the below ground portion of plants that make up 20 to 40 percent of the total plant biomass. In Chapters 8 and 9, research to understand processes within roots and between roots and rhizosphere is undertaken so that understanding of these processes will enable others to predict and finally use this predictive capability to manage and control root growth and rhizosphere ecology.

The ultimate goal of research is to enable others to manage and control outcomes. In Chapter 10, examples of managing and controlling outcomes in small business development in Timor-Leste and fertilizer use in Angola are given.

The global plan of this CRSP was based on the premise that much is known about sustainable natural resource management in general, and soil management in particular, and that the problem is mainly one of low accessibility to, and non-adoption of, existing knowledge and technology. The decision support tools developed by this CRSP and its African, Asian and Latin American partners will continue to help customers with access to information technology and knowledge to allow them to manage and control economic and environmental outcomes in agriculture for many generations to come.

Table of Projects, Institutions and PIs

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 Attanandana, Madonna Casimero	University of Hawaii Kasetsart University Philippine Rice Research Institute
Adoption of the Nutrient Management Support (NuMaSS) Software Throughout Latin America	Honduras, Ecuador, Brazil, Panama	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, Ecuador	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 W. Jones, John M. Duxbury	University of Hawaii University of Florida 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 M. Duxbury	Cornell University Cornell University Cornell University
Genetic Characterization of Adaptive Root Traits in the Common Bean	United States	C. Eduardo Vallejos, Melanie Correll, James W. Jones	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

Summary Sheet

PROJECT TITLE
Soil Management Collaborative Research Support Program

GRANT NUMBER
LAG-G-00-97-00002-00

GRANT PERIOD
February 11, 1997 to September 30, 2008

GRANTEE INSTITUTION
University of Hawaii at Manoa

CONTRACTOR
College of Tropical Agriculture and Human Resources
Department of Tropical Plant and Soil Sciences
1955 East West Road, Agricultural Science Building 205
Honolulu, Hawaii 96822

MANAGEMENT ENTITY
Dr. Goro Uehara, Director
goro@hawaii.edu

Dr. Gordon Y. Tsuji, Deputy Director
gordont@hawaii.edu

PARTICIPATING INSTITUTIONS AND PRINCIPAL INVESTIGATORS
(*See* Table opposite)

COGNIZANT TECHNICAL OFFICER, USAID/EGAT
Charles Sloger, AGR (1997-2005)
Mike McGahuey, Jr., NRM (2005-2007)
Adam Reinhart, AGR (2007-2008)

WEB SITE
http://tpss.hawaii.edu/sm-crsp/

Chapter One

NuMaSS

TESTING, COMPARING AND ADAPTING NUMASS: THE NUTRIENT MANAGEMENT SUPPORT SYSTEM

RUSSELL YOST, DEPARTMENT OF TROPICAL PLANT AND SOIL SCIENCES
UNIVERSITY OF HAWAII AT MANOA, HONOLULU, HI, USA

TASNEE ATTANANDANA, DEPARTMENT OF SOIL SCIENCE
KASETSART UNIVERSITY, BANGKOK, THAILAND

MADONNA CASIMERO, PHILIPPINE RICE RESEARCH INSTITUTE
MALIGAYA SCIENCE CITY OF MUNOZ, PHILIPPINES

UNIVERSITY OF HAWAII

Dr. Rodrigo Badayos of the University of the Philippines at Los Baños explaining use of observable soil features at a site in Isabela to identify soil types and prop erties in the application of NuMaSS.

Table of Contents

NuMaSS – University of Hawaii

OVERVIEW & EXECUTIVE SUMMARY

Phase 1 of the NuMaSS decision support software was comprised of the merger and integration of the ADSS (Acidity Decision Support System) and the PDSS (Phosphorus Decision Support Systems that were developed and tested under the support of the USAID-sponsored TropSoils Project, as the SM CRSP was referred to from 1982 to 1996. These two decision-aids were an implementation and a test of the concept that nutrient management principles are the same globally, but need local, field specific information in order to provide the best diagnoses and recommendations. In addition, these two decision-aids implemented the hypothesis that nutrient management could be structured around the concepts of diagnosis, predictions, economic analysis, and recommendation. The acidity decision-aid captured research and experience in South America and in the Southeastern US for application to the acid soils of Sumatra by the TropSoils project. The phosphorus decision-aid was developed from field studies in western Brazil carried out by North Carolina State University and successfully applied in Sumatra and West Africa, also by the TropSoils project. These two decision-aids thus implemented one mechanism of the South to South sharing of food crop production technology. In order to test this mechanism of sharing phosphorus management, a wider selection of soils was included, such as a selection of representative West African soils, soils from the Philippines, from the Amazon of Brazil, and from Thailand.

During Phase 1, investigators from Cornell University, North Carolina State University, Texas A&M University, the University of Hawaii and each of their host country collaborators developed the Nutrient Management Support System (NuMaSS) software with the specific intent of facilitating the transfer and access of soil nutrient management information between research centers and decision makers at the farm and policy levels; i.e., from farmers and extension personnel to government ministries.

In addition to testing the transferability of biophysical knowledge it was apparent that social and participatory knowledge was needed to fully transfer and empower new producers. Thai researchers recognized that it was necessary to simplify the complex technologies of soil classification, laboratory measures of soil nutrient status and the use of complex biophysical simulation models such that producers could learn and use the results. Experience also demonstrated that in addition to the simplification it was also necessary to empower and stimulate producers' self-awareness and self-reliance in receiving and learning the technology.

The application/adaptation of these decision-aids proved to differ with each country since each had its particular set of capabilities, needs, and national goals with respect to nutrient management. Specific components of the decision-aids were selected by the participating countries varying from only the phosphorus module in Thailand to the NuMaSS model of nitrogen, phosphorus, and liming in the Philippines, to the handheld version of nitrogen, phosphorus, and potassium in Mozambique (NuMaSS-PDA). In order to provide sustained support and maintenance of the distributed software beyond the project end date, a software development company was created and licensed.

Objectives for Phase 2 were:

1. Test and Compare NuMaSS Predictions on Nutrient Diagnosis and Recommendations with Existing Soil Nutrient Management by Farmers, Extension Agents and Researchers.
2. Identify and Refine the NuMaSS Components that Limit Adoption and Usefulness of NuMaSS-based Knowledge.
3. Adapt NuMaSS Data Base and Structure to Reflect Different Types of Users and Different Geographical Regions.

PHASE 2 PROJECT ACCOMPLISHMENTS

In Phase 2 of this SM CRSP, the adoption of integrated nutrient management strategies by adapting NuMaSS through a network of ongoing programs, one in Latin America and another in Africa and Southeast Asia, was implemented by North Carolina State University in the former and the University of Hawaii in the latter. This has had the potential to benefit collaborators in many ways, from improved access to data to available information on the integration of nutrient management-related activities for N, P and/or soil acidity. In their this approach to nutrient management issues, implementation and methodology, numerous parallels exist among various world regions. Shared activities among collaborators from different countries should lead to improved understanding of these issues and consequently improved diagnosis and prescription to meet the needs of the decision makers.

The North Carolina State component was in charge of the merger of the pre-existing ADSS Acidity Decision Support System (ADSS) and the Phosphorus Decision Support System (PDSS), previously developed at the University of Hawaii, and adding a nitrogen component. Additional work was carried out in improving the prediction of lime requirement based on toxic aluminum of acid soils. The outputs of the Hawaii component of NuMaSS, described here, were derived primarily of objectives for updating and adapting the knowledgebase and dissemination and adaption of the knowledgebase to specific needs.

Updating and Adapting Knowledgebase

1. Additions to the knowledge bases of PDSS were the development of a rock phosphate module. This module included new additions to the diagnosis and prediction modules of PDSS, but used the existing economic analysis and recommendation modules. The module was jointly developed by students and collaborators from Thailand (S. Yampracha and T. Attanandana) and Mali (A. Sidibé-Diarra and M. Doumbia). For the first time this module quantitatively predicted the amounts of a specific rock phosphate needed to supply phosphorus for a specific crop on a specific soil and a specific level of soil phosphorus. The results are presented in the dissertations and papers in the publications list.

2. A potassium module was added with the collaboration and funding of the Thailand Research Fund and efforts of student W. Nilawonk and collaborator T. Attanandana, both in Thailand. Initial survey and preliminary work in West Africa was carried out by A. Bagayoko and M. Doumbia of Mali.

Dissemination–Southeast Asia

3. A comprehensive system was built in Thailand of applying site-specific nutrient management to small farm food production. This system, called the Site Specific Nutrient Management (SSNM) system included four components of which decision-aids was one. The components were all focused on field assessment of nutrient status and in providing the best possible scientific information on nutrient requirement to farmers. Components included:
   - Field identification of the soil series, which provides reference information on soil nutrient content and re lease of nutrients and typical climatic conditions for the specific soil series.
   - Field determination of levels of nitrogen, phosphorus, potassium and soil pH by means of the commercially available Thailand soil test kit (Figure 1).
   - Use of decision-aids to synthesize a fertilizer prescription using the specific soil series information and the measured levels of nutrients – first and second component.
   - Specific training of identified farmer leaders in the community to carry out the the first three components and, in addition, train other farmers.

4. A unique aspect of the SSNM was it not only simplified the assessment of nutrient status and requirement such that it could be done in a farmer's field, but it also lead to and began a process of farmer empowerment that could continue. Both the Thailand Research Fund (TRF) and FAO projects supported the dissemination of the SSNM in Thailand.

5. Although the SSNM system was developed in Thailand, portions of it were shared with other collaborating coun-

Figure 1. The Thai soil test kit was used not only in Laos (pictured here measuring pH 5.0), but also in West and Southern Africa.

Figure 2. NAFRI technicians at the Central Soils Laboratory receive instruction from Prof. Tasnee Attanandana (Kasetsart University, Thailand) on the use of a new spectrophotometer purchased by the project. Newly trained Dr. Nivong Sipaseuth (blue shirt) observes.

1) The perennial crop diagnosis and prediction modules developed during NuMaSS Phase 1; 2) The Rock Phosphate module developed during Phase 2; and 3) the Potassium module also developed during Phase 2. The PDSS module implemented several advanced functions such as assessing the uncertainty in predictions using first order uncertainty analysis. The PDSS software also implemented the Bayesian approach to cumulative probability of the "soft" or uncertain information that was later transferred to NuMaSS.

6. Initial successes fueled the rapid expansion of maize and soybean in both locations. Recent testing has taken place in the previously unproductive regions of Xiengkouang Province where it was reported that neither maize nor rice could be produced. Recent results of Lao graduate students indicate that yields of six tonnes of maize are possible when the nutrient deficiencies of phosphorus and zinc are corrected (Figure 4) and the soil pH is increased with limestone applications according to NuMaSS and PDSS diagnoses and predictions.

tries. Collaborators from the National Agricultural and Forestry Research Institute (NAFRI) (Figure 2) of the Laos PDR also expressed interest, adapted and tested both NuMaSS and PDSS software in new research in the uplands, specifically on maize in the North near Vientiane and soybean and maize in the South near Champassak province (Figure 3).

Both the NuMaSS and PDSS software were maintained and updated by the NuMaSS/Hawaii project. Hawaii was responsible for the P module of NuMaSS and used the PDSS software as the first recipient of newly developed modules including:

Figure 3. Field visit during the Regional SM CRSP workshop in Champassak Province, Laos, 2007. Participants from the Philippines (4), Thailand (2) attended, as well as SM CRSP ME Director Goro Uehara.

Figure 4. Mr. Dounphady, from NAFRI, Laos, a MS candidate in Soil Science at Kasetsart University, photographs severe zinc deficiency in his field experiment in Xiengkouang Province.

7. The NuMaSS software, a product of the first phase of the NuMaSS project, was used for extensive testing in the Philippines after initial testing by M. Aragon of PhilRice, Maligaya and through collaboration with the International Rice Research Institute (IRRI). The technique of field identification of the soil series (the first component of SSNM, which was developed in Thailand) was readily accepted and with the assistance of both PhilRice (M. Casimero) and the University of the Philippines at Los Banos (R. Badayos) the system was also extended to include paddy soil as had subsequently been done in Thailand and is being implemented in at least four provinces at last count.

8. An impact analysis carried out in 2007 indicated that with NuMaSS recommendations it was possible to grow maize, peanut, and mungbean on lands previously considered incapable of growing such food crops (Figure 5). Results were supported by the local government units (LGU) and dissemination programs were in place to support the over 300,000 ha annually grown to maize in the province of Isabela alone.Neighboring provinces of Cagayan and Nueva Vizcaya are also implementing lime distribution programs. The impact analysis conservatively projected over the next 40 years values that $45 million US will result from the research project investment of $300,000. Limestone is now commercially available, whereas it was unknown and unheard of when the project began.

Dissemination–West Africa

9. In Mali, collaboration was largely through training of scientific personnel and included two PhD programs for IER scientists, one on rock phosphate (A. Sidibé-Diarra) as described further on and the other on laboratory methods of analysis including Loss on Ignition and the new technology of Visible Infrared Spectroscopy (H. Konaré). A possible MS/PhD program was initiated but could not be completed due to funding deadlines (A. Bagayoko). Results from Mali and Senegal indicated widespread K deficiency with some soil samples containing no measureable plant available K by conventional means.

Figure 5. Former CIP and Michigan State economist, Dr. Tom Walker, PhilRice Sociologist Rachel Acda, and Technician Jenny Fernandez assist in farmer interviews as part of the impact analysis in 2007.

10. In Senegal, an initial survey of crop productivity, soil type, and fertilization practice from 148 farms from southern Senegal was initiated as a first step in assessing nutrient manage needs. The results indicated that median yields of major food crops were incredibly low (in kg/ha): millet 300-500, sorghum 150-300, peanut 300-600 and maize 600-800. Essentially no fertilizers were applied to the surveyed crops. Field studies on selected farmer sites indicated that yields of millet could be increased to 600-800 kg/ha and peanut yields increased to 1200 to 1800 kg/ha with minimal fertilization. It was clear that the "nutrient mining" or growth of crops without nutrient additions nor nutrient replenishment in the already nutrient-depleted soils was and continues to be a major constraint to food crop yields.

Figure 7. Planning an on-farm experiment comparing NuMaSS recommendations with farmer practice – Mozambique.

11. Portions of the SSNM technology were also introduced into West Africa as both soil test kits and training events on their use in Senegal and The Gambia. A total of some 30 kits were donated to the local national research institutes, ISRA (Senegal) and NARI (The Gambia). Workshops were held in The Gambia (Figure 6) and included their neighbor SM CRSP Collaborator, Modou Sene. Numerous assistance and relief organizations participated in the workshops and became aware of the serious limitations on food crop productivity resulting from lack of fertilization.

Figure 6. Students at the Mussa Bin Bique University, Maputo, Mozambique learn to use the soil test kit developed in Thailand, at Kasesart University. Dr. Momade Ibraimo is teaching his students after attending one of the workshops held at by the SM-CRSP project.

12. In Ghana, field studies on peanut cropping rotations in the northern part of the country indicated that NuMaSS predictions of fertilization increased yields more than current recommendations or current farmer practice.

Dissemination–Southern Africa

13. In Angola and Mozambique, portions of both the SSNM technology and the NuMaSS and PDSS software were introduced through the assistance of additional funding from missions (Angola and Mozambique), and the INTSORMIL CRSP (Mozambique). The ProPlanalto Project (a collaboration among several agencies including USAID, Texaco and World Vision), with initial support from the USAID mission in Angola, purchased some 30 units of the soil test kit. SM CRSP scientists from both Hawaii and North Carolina provided technical support and assistance to the ProPlanalto project (Figure 7), introduced the NuMaSS and PDSS decision-aids, and ultimately contributed to the analysis, summary, and publication of ProPlanalto project results (Asanzi et al., 2006) (Figure 8).

Figure 8. One of many potato variety experiments installed by the ProPlanalto Project under the leadership of Dr. Chris Asanzi (left) in Angola. Efforts were underway to initiate local production of seed potatoes of the best varieties.

14. As a result of this effort soils were sampled and nutrient status assessed for the first time after 30 years of civil war. A similar disruption of food production occurred in Mozambique although the civil war lasted only some 20 years. The outstanding potential for food production of high plateau region of Southern Angola was amply demonstrated in high yields of potato, beans, and maize (Figure 9).

15. The same components of the SSNM technology, specifically soil test kits, and the NuMaSS and PDSS decision-aids were introduced in Mozambique by workshops that were conducted with assistance of Lusophone collaborators via scientific exchange, for example from scientists from Cabo Verde. Our collaborators, including a former University of Hawaii graduate supported by an INTSORMIL CRSP development and training program, have conducted internal workshops of soil test kits and field studies testing and demonstrating NuMaSS and PDSS diagnosis, predictions, and economic analysis. A recent International Fertilizer Development Center program on fertilizer marketing has been implemented in Mozambique and is also testing NuMaSS and PDSS performance in key agricultural zones of the country. The Mozambique collaborators have formed a consortium of scientists from Mozambique, Malawi, Zambia and Zimbabwe exploring and testing NuMaSS and PDSS predictions in each of the four countries. The Mozambique program of implementing the new Green Revolution in Africa has been taken up by the Minister of Agriculture of the country and the efficient use of fertilizers is one of the components.

16. The NuMaSS decision-aid components of Nitrogen and the PDSS decision-aid components of phosphorus and potassium have been combined into the NuMaSS-PDA, which is a smaller, yet more comprehensive version of both decision-aids. This software has been developed by a new venture from the University of Hawaii called MobileSoft International, LLP, which is the licensed developer and distributor of the NuMaSS-PDA software. This new software runs on handheld computers and provides language interfaces in French, Portuguese, English, with Tagalog (Philippines) and Tetun (Timor-Leste) soon to follow. Sales of the software have been to NGOs that have participated in previous NuMaSS and PDSS workshops.

17. The food security landscape in our collaborating countries has changed dramatically from 2007 to 2008 with the higher costs of oil, food, rice and, fertilizer. The SM CRSP

Figure 9. Addressing the extreme food shortage caused by the 30 years of civil war, technicians of the Pro-Planalto project carried out more than 35 field experiments on varieties and fertilization of the food crops potato, maize, and beans under the direction of World Vision scientist Chris Asanzi, third from the right (see Asanzi et al., 2006). One of the experimental sites, Kapunge, shown here, was also a site of the farmer-to-farmer visits guided by Ms. I. Baptista, Cabo Verde.

projects including the NuMaSS component have made solid contributions to the resolution of some of the food security problems in our collaborating countries as illustrated by the Philippine example of maize production, rice and maize in Thailand, maize in Laos, as well as increases in food production in Angola and Mozambique.

HIGHLIGHTS OF ACCOMPLISHMENTS

Southeast Asia

One of the primary results was a new awareness of the acidity of upland soils of the Philippines. New maps indicated that some 7 to 9 million hectares (ha) of upland soils were acid, for which little appropriate soil management technology existed. The challenge at the time was that liming technology, while well developed elsewhere in the tropics and subtropics, was not well developed in the northern Philippines (Figure 10). NuMaSS testing called attention to the serious acidity in the province of Isabela, where lime was not commercially available. With assistance from the Local Government Unit and subsequently the direction of the Region II, which includes four provinces containing acid soils, major liming programs are now being implemented in four of the provinces. In the province of Isabela alone, some 300,000 ha are cropped to maize each year. Yield increases due to lime application to maize averaged 1 to 1.5 tons/ha. The long-term impact of liming appears enormous.

In Thailand, the nutrient management problem was the opposite – farmers were applying excessive amounts of fertilizer, both nitrogen and phosphorus. Rather than adopt NuMaSS, Thai collaborators adopted separate components of NuMaSS, namely PDSS, as they had already developed their own N management software and only needed the P knowledge in algorithmic form. In addition, Thai collaborators invited and supported the development of a potassium algorithm, which was incorporated into the PDSS software and in the recently released NuMaSS-PDA software. The Thai version of site-specific nutrient management (SSNM) included the simplification of three technologies (field identification of soil series, soil test kits, and decision-aids) and the empowerment training of farmers to better understand and control the crop production systems. Dissertation studies further adapted and improved the SSNM by addressing specific problems and constraints.

Figure 10. Site of one of the techno-demos illustrating the substantial benefits of liming acid soils of Isabela Province to increase maize yield. The province alone plants over 160,000 ha of maize per year. Technicians Maria, Jenita, and Isabela assist the producer with the experiments.

For example, one dissertation indicated that locally available rock phosphate contained large amounts of limestone, which neutralized soil acidity limiting its use. Another dissertation indicated that residual nitrate was substantial in many Thai maize soils and should be considered in reducing fertilizer N requirements. A dissertation study of potassium indicated that Ca resin extraction was an excellent predictor of K availability on soils with large amounts of nonexchangeable K. The SSNM, while initially developed for maize, was extended to sugarcane and rice. With the current crisis in food prices and fertilizer costs, Thai collaborators were asked by the government to take a major role in revising fertilizer recommendations for maize, rice and eventually other crops. The Department of Land Reform is applying the SSNM to five provinces in the Northeast and 18 provinces in the Central Plain of Thailand in 2008.

In Laos, major limitations to food crop productivity again differed. Similar in some respects to the case in the Philippines, recent surveys indicated acid, upland soils, yet no technology was locally in place to manage such soils for food crops. The province of Xiengkouang, for example, was without a technology to produce maize. Recent studies by a Laotian student for his MS thesis showed for the first time that maize could be produced if the severe multiple nutrient deficiencies were corrected. The potential to produce soybean and maize in southern Laos was evaluated and appears highly feasible. The Laos case was also similar to the Philippines in that fertilizers were scarcely available prior to 1995 and the appropriate technology in their application did not exist.

The nutrient management support system (NuMaSS) project has been carried out in Laos since 2003 by the Agriculture Land Research Center. The main activities of the project were field experiments, on farm trials and the transfer of technology to the farmers in many parts of the country. The outcomes of the project were able to increase maize grain yield from 3.5 to 6.0 t/ha, and 0.6 to 0.9 t/ha for mungbean. From the training and participation in farmer-to-farmer visits to Thai maize farmers, the Lao farmers gained nutrient management experience, learned about appropriate rates of fertilizer application and proper crop planting technique. Maize has been the second most important crop after paddy rice, with 29,000 ha grown in 1976 increasing to 52,000 ha in 2003 and 113,800 ha in 2006. Five provinces in the North and Central portions of the country are now in rapid expansion of maize production.

West Africa

Unsustainable production of food and loss of food security continues throughout the Sahel of West Africa. Previous experience in West Africa had indicated that nutrient mining continues unabated and it continues to reduce food crop productivity at a steady rate. Nutrient mining also causes a loss of soil organic carbon that is even more serious – not only are nutrients lost but soil capacity to retain nutrients and water is also lost. Soil carbon will be discussed in the other SM CRSP final reports found in this publication, notably Carbon Sequestration, but it is intimately related to the prevalent and extensive mining of nutrients, now recognized as a serious problem.

The NuMaSS decision-aid was adapted to West African conditions and results indicated that no change was needed to adapt the phosphorus decision support system (PDSS) component of it to West Africa. Tests in Mali with the NuMaSS demonstrated that the decision-aid generally provided more economic fertilizer requirements than three other approaches: 1) Quadrant, 2) Nutrient balance, and 3) QUEFTS. Surveys of nutrient status in Mali and Senegal indicate major deficiencies of potassium (K) exist. NuMaSS provided economic recommendations in peanut-based cropping systems in Ghana. NuMaSS was converted to a NuMaSS-PDA software for use on handheld computers.

A quantitative approach to estimating rock phosphate requirements was proposed and field-tested by a Malian scientist in Senegal, Mali, and Niger and pointed out the limitations to use of rock phosphate in West Africa.

Increases in fertilizer efficiency were made possible by improved capture and use of rainfall through the use of soil and water conservation technology in Mali and The Gambia.

Lack of fertilizer and fertilizer technology were not the only constraints on food production in Africa. Nutrient management in was dramatically reduced after the 1994 currency devaluation. Fertilizer use in The Gambia, for example, dropped from one of the highest in Africa to one of the lowest as a result of the exorbitant prices of fertilizer after devaluation. Thus in West Africa the challenge was to increase the efficiency of fertilizer use.

Southern Africa

Nutrient management issues in Southern Africa – Angola and Mozambique – differed markedly from those in West Africa. Both countries are recovering from devastating civil wars and suffer from either non-existent or a destroyed fertilizer/commercial infrastructure. Angola's 30 years of war ended in 2002, while the civil war in Mozambique lasted approximately 20 years. Both countries were food insecure at the beginning of the project and only recently have begun to improve food security through improved food crop management which includes managing soil nutrients. The NuMaSS decision-support system was introduced and tested in Angola and Mozambique in 2004 and 2005. The testing in Angola was short-lived due to change in USAID mission priorities. Support and stimulation of an improved fertilizer industry as a foundation for a national food policy to promote food security continues in Mozambique. Not widely known is the recent challenge for Africa to implement a modern, sustainable version of the Green Revolution. A former MS Student supported by INTSORMIL and the NuMaSS project has introduced the Thai soil test kit, the NuMaSS and PDSS decision-aids and is now conducting regional fertilizer experiments testing the adaptability of the NuMaSS-PDA software for Mozambique conditions (Figure 11).

Figure 11. Scientist Isaurinda Baptista (blue cap) from Cabo Verde illustrates the use of soil test kits from Thailand to scientists in a Mozambique workshop.

LESSONS LEARNED

Decision-aid software needs vary with country and the nutrient management conditions in each country. Some countries need guidance on beginning fertilization programs, some, however, need guidance on ways to apply technology to reduce excessive applications, becoming more economical and environmentally friendly. In several cases, the decision-aids drew attention to nutrient management needs not previously recognized.

Decision-aid software has been shown to be highly useful in transferring nutrient management technology through its formulation as diagnosis, prediction, economic analysis and recommendation. Use of the software has resulted in the users learning and structuring their techniques of analysis and problem -solving. Consequently, subsequent decision-aids should include this consideration in their development and user interface.

Testing and modifying decision-aids have been effective tools with which to structure, organize and focus graduate research. A great deal of literature review, research results and interpretations can be captured by decision-aids and they serve as excellent tools to help shape research and capture results.

NEXT STEPS

A for-profit software development corporation, MobileSoft International, LLP, has been created and incorporated to adapt, develop and maintain agricultural software. The company has leased the NuMaSS software from the University of Hawaii to re-design and implement a version of the NuMaSS desktop software to become the NuMaSS-PDA, which is a deployment of the N, P, and the newly developed K module. MobileSoft International has developed a highly efficient language translator that permits the hand-held software to be presented to users in the following languages: English, French, Portuguese, Tagalog, Tetun and others as might be needed. The software and "hardened" PDA are presently for sale and transactions have been completed with NGOs in Southern Africa.

A scholarship foundation has been created in Thailand to provide scholarships and training support for agricultural students of Laos, Cambodia and Myanmar. Four students are presently being supported by the foundation.

A UH faculty member will be spending a year in follow-up teaching at Eduardo Mondlane University and research at the Instituto de Investigações Agronômicas de Mozambique (IIAM) in Maputo, Mozambique supported by a Fulbright scholar fellowship.

Future development, maintenance and expansion of agricultural software are now on a for-profit basis and will be handled by MobileSoft International, LLP.

PARTICIPATING AND COLLABORATING SCIENTISTS & INSTITUTIONS/ORGANIZATIONS

National Agricultural Research Systems (NARS)

Angola

Faculdade de Ciencias Agraria
S. Henriques
David Kiala

Instituto Investigacão
F. Almeida
Joaquim Cesar

USAID
Gomes Cambuta
Kenneth Lyvers
Chris Smith

World Vision
C. Asanzi

Ghana

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

University of Ghana
Samuel Adiku

Laos

National Agricultural and Forestry Research Institute (NAFRI)
Kouang Doungsila

Mozambique

Instituto de Investigacões de Agricultura de Mozambique (IIAM)
C. Bias
Pedro Comissal (Nampula)
Edouardo Joaquim (Manica Province)
Ricardo Maria
Candida Xavier (Maputo)
S. Xerinda (Chokwe)

Philippines

Leyte State University
Angela Almendras
Raquel Serohijos

Philippines Rice Research Institute
Rachelle Acda (Maligaya
Madonna Casimero
Dario Cidro
Jocelyn de la Cruz (Ilagan)
Rona Dollentas
Rodolfo Escabarte (Mindanao)
Alice Mataia (Maligaya)

University of the Philippines at Los Banos
Rodrigo Badayos

University of Southern Mindanao
Flor Nicor
Adeflor Garcia

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)
Aminata N. Badiane
B. Diagana
Mbaye Diaw
A. Dieng
P.N. Diéye
Mousso Diop
O. Djedjou
A. Fall
M.D. Faye
Saliou Faye
Fatou Gueye
M. Guéye (ISRA-IRD)
M. Khouma
A. Mankor
Samba N'Diaye
M. Ndiaye
C.M. Ndione
A. Niang
Pape S. Saar
Modou Séne

Thailand

Department of Agriculture
Santi Thirporn

Department of Ag. Ext. (DOAE)
A.Charoenaksiri

Department of Land Development (DLD)
B. Boonsompopphan
S. Kongton
T. Vearasilp

Mahasarakham University
P. Khangkhun
M. Wongsawas

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

Kasetsart University
Tasnee Attanandana

Eco-community Vigor Foundation
P. Verapattananirund

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

TRAINING AND DEGREE PROGRAMS

Degree Programs

Year	Name	Degree	Gender	Institution	Home Country
2006	Ricardo Maria	MS	M	University of Hawaii	Mozambique
2008	A. Sidibe-Diarra	PhD	F	University of Hawaii	Mali
2005	Abibou Niang	MS	M	Université Cheikh Anta Diop de Dakar (Senegal)	Senegal

Non-Degree Programs

Name	Home Country	Gender	Dates
A. Bagayoko	Mali	M	2006
Sukunya Yampracha	Thailand	F	2006

Workshops

Title	Date	Location	Gender
NuMass	3/12-15/02	Lomé, Togo	60M,2F
NuMass	2/17-21/03	Bambey,Senegal	13M,5F
NuMass	9/2004	Bambey, Senegal	15M,3F
NuMass	12/6-9/04	Bambey,Senegal	46M,2F
NuMass	l/2005	Laos	17M,18F
NuMass	1/24-25/05	Philippines	3M.3F
NuMass	1/24-26/06	Philippines	10M,15F
NuMass	07/17-19/06	Laos	5M,25F
NuMass	1/8-14/07	Laos	25M,15F
NuMass	8/28/07	Laos	22M,11F

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Chapter Two

NuMaSS

ADOPTION OF THE NUTRIENT MANAGEMENT SUPPORT SYSTEM (NUMASS) SOFTWARE THROUGHOUT LATIN AMERICA

T. JOT SMYTH, DEPARTMENT OF SOIL SCIENCE
NORTH CAROLINA STATE UNIVERSITY, RALEIGH, NC, USA

DEANNA L. OSMOND, DEPARTMENT OF SOIL SCIENCE
NORTH CAROLINA STATE UNIVERSITY, RALEIGH, NC, USA

NORTH CAROLINA STATE UNIVERSITY

Potato yield response in 2005 to fresh and residual P fertilizer inputs in an Andisol at Santana, Ecuador. The first number indicates the amounts of P in kg P_2O_5/ha that were applied to the preceding potato crop in 2004. The second number indicates the amounts of P that were applied at planting of the current crop.

Table of Contents

OVERVIEW & EXECUTIVE SUMMARY

In 1997, nutrient management decision support system software for crop production was limited to two prototypes (acidity and phosphorus decision support systems) and a paper outline for a system addressing N. Each prototype functioned independently and was largely based on the extensive research data that the Soil Management CRSP, also referred to as TropSoils, accrued on these contraints throughout tropical regions of Africa, Asia and Latin America during the previous decade. A conceptual strength of all these prototypes was that the decision structure was designed to address field- and crop-specific acidity, and N and P constraints throughout the tropical regions of the world. This approach provided fundamental principles and sets of rules that had global potential and implications towards identifying and correcting soil acidity and nutrient constraints.

Our focus during Phase I was to produce, test and disseminate an integrated decision support system software tool, the Nutrient Management Support System (NuMaSS) for purposes of diagnosing symptoms associated with soil acidity, N and P constraints, recommending remedial correction and assessing the economic impacts of lime and nutrient inputs.The NuMaSS software was programmed to run on existing and future versions of the Windows operating system (OS), to address all three soil constraints simultaneously, provide transparency as to how recommendations are derived and be both friendly to novice users while also adaptable to fine-tuning for local conditions by experienced users.

To develop NuMaSS, a multi-disciplinary team of 17 scientists from five U.S. universities (Colorado State, Cornell, Hawaii, N.C. State and Texas A&M) worked jointly with national and international institute collaborators at three intensive testing areas, each region representing a distinct agroecological zone in the tropics (millet-cowpea production on Alfisols in the semi-arid region of Cinzana, Mali; corn-soybean-peanut-upland rice production on Ultisols in the wet-dry region of Ilagan, Philippines; and heart-of-palm production in peach palm plantations on Andisols/Ultisols in the humid tropical region of Costa Rica). Each region provided real life situations with potential to alleviate soil acidity, N and P management problems, and to test and refine NuMaSS prototypes.

The Latin American site in Costa Rica focused on expanding our knowledge base on nutrient management for grain, tuber and forage crops into perennial tree crop system, using peach palm plantations for heart-of-palm production.

We relied heavily on an extensive network of soil nutrient management ‘experts’ throughout the tropics, many of who were graduate alumni of CRSP research during the previous decade. They evaluated, critiqued and identified essential modifications to each interim software version, and contributed their local knowledge to the software’s database. Feedback from this ‘participatory-development’ approach ensured that the software was relevant and practical at both the local and global scales.

NuMaSS has three modules to assist users in making nutrient management decisions for crops under user-specified field conditions. These modules include:

1. The *Diagnosis* module addresses the question of whether acidity, nitrogen or phosphorus problems exist based on observations provided about geographical location, climatic conditions, soil type, previous crop yield and nutrient management, nutrient deficiency symptoms and indicator plants. Soil and plant analytical data are considered, if available, but are not required in the minimum data set described in Table 1.
2. The *Prediction* module recommends lime and nutrient inputs to correct identified acidity, nitrogen and phosphorus problems that could limit achievement of the yield level specified by the user for the selected crop. Lime and fertilizer recommendations provided by NuMaSS account for differences in available nutrient sources and nutrient requirements among crop species and cultivars, but user input of a minimum soil analytical data set is required (Table 1). The soil analysis data are restricted to measurements routinely determined by soil testing laboratories.
3. The *Economics* module estimates net returns to applied nutrients. Users can compare different types of elemental fertilizers, available commercial blends and organic sources. For each combination of nutrient sources, NuMaSS will estimate amounts of inputs for either the best profit or the best yield. Economic estimates can also be constrained by specifying a maximum amount of fertilizers to be applied or a given amount of cash to be invested in fertilizers and application costs. For each of the

Table 1. Minimum data input requirements for each NuMaSS module and soil nutrient constraint.

<table>
<tr><th colspan="4">Soil Nutrient Constraint</th></tr>
<tr><th>Module</th><th>Nitrogen</th><th>Acidity</th><th>Phosphorus</th></tr>
<tr><td rowspan="3">Diagnosis</td><td colspan="3">---------- Location and climatic regime ----------</td></tr>
<tr><td colspan="3">---------- Intended crop ----------</td></tr>
<tr><td></td><td>Crop critical % Al saturation</td><td></td></tr>
<tr><td rowspan="7">Prediction</td><td colspan="3">---------- Target yield ----------</td></tr>
<tr><td colspan="3">---------- Bulk density ----------</td></tr>
<tr><td colspan="3">---------- Fertilizer application depth ----------</td></tr>
<tr><td>Grain: stover ratio</td><td colspan="2">----------% clay or textural class ----------</td></tr>
<tr><td>Grain and stover % N</td><td>Exchangeable Al</td><td>Soil test P value</td></tr>
<tr><td>Fertilizer N use efficiency</td><td>Effective cation exchange capacity</td><td>Soil test P method</td></tr>
<tr><td colspan="2">----- Amount of organic inputs -----</td><td>Fertilizer application method</td></tr>
<tr><td rowspan="4">Economics</td><td colspan="3">---------- Maximum achievable yield for region ----------</td></tr>
<tr><td colspan="3">---------- Crop price ----------</td></tr>
<tr><td colspan="3">---- N and P Fertilizer source; lime, N and P fertilizer prices ----</td></tr>
<tr><td colspan="3">---------- Lime and fertilizer application costs ----------</td></tr>
</table>

various user-selected scenarios, NuMaSS estimates whether there will be a surplus or deficit in applied nitrogen and phosphorus.

The integration of nutrient diagnosis, prediction and economics in NuMaSS empowers users to compare and make choices among different field conditions, cropping strategies and nutrient source alternatives. The software contains an extensive database assembled from published and gray literature on field and laboratory investigations conducted throughout Africa, Asia and Latin America for the following crops: bambarra groundnut, cassava, cotton, cowpea, peanut, phaseolus bean, maize, mung bean, pearl millet, potato, sorghum, soybean, upland rice, wheat, yam, and forage grasses and legumes. A module for tree crops is also included, using peach palm for heart-of-palm production as the test crop (Figure 1).

Version 2.0 of the NuMaSS software was a product of Phase I and released in October 2002, after beta-testing by 65 network participants from 24 countries via regional workshops in Africa (Togo), Asia (Philippines) and Latin America (Costa Rica). Feedback from the evaluation network and field testing in those host countries' intensive testing areas guided software refinements and modifications.

Objectives for Phase 2 were:

1. Test and Compare NuMaSS Predictions on Nutrient Diagnosis and Recommendations with Existing Soil Nutrient Management by Farmers, Extension Agents, and Researchers.
2. Identify and Refine the NuMaSS Components that Limit Adoption and Usefulness of NuMaSS-based Knowledge.
3. Adapt NuMaSS Database and Structure to Reflect Different Types of Users and Different Geographical Regions.

PHASE 2 PROJECT ACCOMPLISHMENTS

Our focus during Phase 2 was to support the adoption of NuMaSS-based knowledge via a network of on-going programs throughout Latin America with potential to benefit from the improved access to information on soil N, P and/or acidity management. The primary target groups within the policy-to-farmer decision-making continuum were the national research and

Figure 1. Farmer loading harvested peach palm stems (stack on ground) on to animal for transport to processing plant; background shows peach palm plantation on Andisols in Costa Rica.

extension services. These groups provided, interpreted and had immediate access to the location-specific soil and crop data required to develop nutrient recommendations and economic evaluations from the NuMaSS knowledge base. Collaborators from eight countries in Latin America (Mexico, Honduras, Nicaragua, Costa Rica, Panama, Ecuador, Bolivia and Brazil) provided field tests of the software's performance for 10 of the 17 grain, tuber and forage crops considered by NuMaSS across nine soil taxonomic orders distributed among three major climatic regimes (semi-arid, wet/dry and humid tropical). Our field tests in Latin America were designed to compare NuMaSS recommendations with those in local use and to produce local crop- and soil-specific coefficients that would enhance software performance at the regional level.

During this phase of the project, our activities with collaborators focused on:

- Testing and comparing NuMaSS predictions to those currently in use;
- Identifying and refining software components that limit NuMaSS adoption and use; and
- Monitoring the local adoption process within regional domains.

We began in the first year by visiting each potential group of collaborators to introduce them to NuMaSS, identify their interests and potential contributions, assess existing relevant data, and define investigations needed to address their local information gaps. Thereafter, annual site visits and extensive e-mail communication provided technical backstopping support to collaborators' region-specific tests, their impacts on NuMaSS predictions and, as desirable information was achieved, training on and local adoption of the NuMaSS software.

Diversity of Nutrient Constraints, Crops and Soils in NuMaSS Testing Throughout Latin America

One of the outcomes of NuMaSS adoption in Latin America was to test software performance under numerous combinations of crops, soil types, climatic regimes and nutrient constraints. As shown in Tables 2-4, a wide variety of situations were considered and encompassed: 10 crops, nine orders of the U.S. Soil Taxonomy, three climatic regimes and five nutrient constraints. Although K and S constraints are not considered by NuMaSS, we addressed these nutrient problems locally whenever present to ensure optimum crop growth response to lime, N and P. A satisfactory performance in NuMaSS diagnoses and recommendations with these crops in Latin America would be indicative of a positive outcome in other regions of the tropics with similar soil and climatic conditions.

Table 2. Diversity of crops involved in NuMaSS testing and adoption activities throughout Latin America.

	Crops									
Country	Cassava	Corn	Cotton	Cowpea	Potato	Sorghum	Soybean	Rice	Wheat	Pastures
Mexico		√	√			√				
Honduras		√								
Nicaragua		√								
Costa Rica					√					
Panama		√						√		
Ecuador					√					
Bolivia					√				√	
Brazil	√	√		√			√	√		

Table 3. Soil orders in the U.S. Soil Taxonomy System represented among testing sites throughout Latin America.

	Soil Order								
Country	Alfisols	Andisols	Aridisols	Entisols	Inceptisols	Mollisols	Oxisols	Ultisols	Vertisols
Mexico			√			√			√
Honduras				√	√				
Nicaragua				√	√				
Costa Rica		√							
Panama	√							√	
Ecuador		√							
Bolivia					√				
Brazil	√						√	√	

Table 4. Climatic regimes and soil nutrient constraints among testing sites throughout Latin America.

Country	Humid Tropical	Semi-arid	Wet/Dry	Acidity	N	P	K	S
Mexico		√			√	√		
Honduras			√		√		√	√
Nicaragua			√		√		√	
Costa Rica	√					√		
Panama			√	√	√	√	√	
Ecuador			√			√		
Bolivia			√		√	√		
Brazil	√		√	√	√	√	√	√

Establishing Crop and Soil Coefficients within Regional Domains

As shown in Table 1, NuMaSS recommendations for lime, N and P require certain crop- and/or soil-dependent coefficients. Examples are crop critical % Al saturation of the soil ECEC, grain:stover ratios and tissue % N, maximum achievable yield and fertilizer N use efficiency. Fertilizer P recommendations are based on algorithms which estimate critical soil test P levels and soil P buffer coefficients from soil clay content. In the absence of local information on these coefficients, NuMaSS provides "default" values based on existing information assembled in the data tables. However, the software design enables users to override these values with locally-derived coefficients. A significant portion of our field and laboratory testing activities with collaborators involved the development of these coefficients for their specific crop varieties and soils, as well as comparing improvements in NuMaSS recommendations relative to those with the standard "default" values.

Variations in corn variety plant- and soil-N coefficients derived from local testing at various sites in Honduras and Nicaragua are shown in Table 5. Also shown are the default values that NuMaSS would recommend for these same locations in both countries. The importance of using crop- and location-specific data is appreciated by comparing NuMaSS default values with values achieved with each variety-location combination. In subsequent tests conducted with local NGOs to compare farmer fertilization practices with NuMaSS recommendations, our collaborators were able apply to these locally derived coefficients to fine-tune software fertilizer N recommendations. Similar sets of software N coefficients were also developed for corn varieties/hybrids and upland rice varieties in the state of Pará, Brazil and Azuero/Veraguas, Panama. Trials with sorghum in Tamaulipas, Mexico led to the recommendation that fertilizer N should only be used when targeted yields are > 2000 kg/ha. Nitrogen coefficients in Bolivia were developed for the *andigena* sub-species of potato, whereas values in the NuMaSS data tables are for the 'European' types of potato.

Table 5. Nitrogen coefficients for corn varieties/hybrids in selected regions of Honduras and Nicaragua, and default coefficient values suggested by NuMaSS.

	Country and Location						NuMaSS
	Honduras				Nicaragua		Default
Variable	Candelaria	Catacamas	Talgua	Yorito	S. Dionisio	S. Rafael	Values
Variety	*D. guayape*	*HS 15*	*DK53*	*HB 104*	*NB 6*	*N. blanco*	
Yield w/o N, kg ha-1	1700	5600	5200	1400	3000	2450	2468
Max. Yield, k kg/ha	4100	5600	7400	3100	4100	6600	3326
Optimum Fert. N, kg/ha	50	0	105	95	60	125	32
Grain:Stover	0.69	0.77	1.34	0.77	0.76	1.17	0.84
% N Grain	1.24	1.47	1.44	1.40	1.68	1.43	1.24
% N Stover	0.51	1.15	0.65	0.71	0.70	0.51	0.57
Soil N, kg/ha	40	154	75	36	66	46	40
Fert. N Efficiency, %	57	--	49	30	32	74	44

Several collaborator trials also provided comparisons between soil P critical levels found greater deviations between NuMaSS predictions and locally-derived values (Table 6). Typically, we have soil P critical values and buffer coefficients in soils with less than 20% clay. The impact of these differences can lead to significant changes in fertilizer P recommendations. For example, a recommendation for band-applied P to cowpea in the sandy Ultisols from Pará, Brazil would be 16 kg P_2O_5/ha with the default NuMaSS prediction as opposed to 39 kg P_2O_5/ha with locally-derived soil P coefficients.

We have also investigated the soil acidity constraint in Brazil and Panama. Long-term lime trials in Pará, Brazil have established crop critical % Al saturation values in the sandy Ultisols. These values range from 15% for five corn varieties and hybrids commonly cropped in the region to variety-specific values for two cowpea cultivars (10% for BR3 and 38% for 'Milênio'). Contrastingly, we have not found corn or soybean yield response to lime in clayey Oxisols of Pará, Brazil during three consecutive years of cropping after conversion from degraded pastures. This is a significant savings in crop production costs for a region where the same soils under native rainforests have pH values of 4.2 and > 50% Al saturation. Laboratories in Panama have been using NuMaSS-based lime recommendations for upland rice and tuber crop production in their Ultisols since the release of the Acidity Decision Support System in the late 1970s.

Table 6. Comparison of soil P critical levels and buffer coefficients predicted by NuMaSS with values derived from local field trials.

	Soil	%		P	P Crit. Level, mg/dm^3		P Buffer Coefficient	
Location	Order	Clay	Crop	Method	Observed	Predicted	Observed	Predicted
Pará, Brazil	Ultisol	7-14	Corn, cowpea	Mehlich-1	13	22	0.350	0.640
			Cassava	Mehlich-1	6	9	0.350	0.640
	Oxisol	76	Corn, soybean	Mehlich-1	8	8	0.186	0.157
Mato Grosso, Brazil	Ultisol	36	Pastures	Mehlich-1	3	8	0.110	0.157
Azuero, Panama	Alfisol	42	Corn	Mehlich-1	13	8	0.680	0.157
Toralapa, Bolivia	Inceptisol	18	Potato	Mehlich-1	82	39	0.610	0.490
Tamaulipas, Mexico	Aridisol	30	Sorghum	Olsen	<11	15	--	--

Refinements to the NuMaSS Software

Two modifications in the final version (2.2) of the software will improve local adoption and use.

Database editor module. Users can now "customize" software data tables by including crop coefficients for their specific varieties/hybrids and soil coefficients derived from investigations within their specific regional domains. They can also include soil test data for representative soils in their regions and new fertilizer blends available in the local markets. This enables the local use of the software, wherein the "default" values of NuMaSS are based on the local findings rather than the software's original and global data tables.

Translation to Portuguese and Spanish. Users can now choose to use NuMaSS in English, Portuguese or Spanish, thus eliminating the pre-requisite of an English proficiency in prior software versions. Software manuals and user guides are also provided in the three languages.

These two modifications facilitated user adoption of NuMaSS throughout Latin America. Over 300 users selected by our collaborators received hands-on training with NuMaSS, through 10 regional workshops. These users included researchers, university/technical school professors and their students, extension agents, NGO technicians, consultants, municipal planners/administrators, fertilizer dealers and bank loan agents (Figure 2). The project's final version of NuMaSS has been downloaded from a website by almost 500 individuals, of which 92 percent were from Latin America.

HIGHLIGHTS OF ACCOMPLISHMENTS

Impacts of NuMaSS Adoption in Latin America

Adoption and adaptation (field and laboratory development of crucial coefficients) of the software to regional

Figure 2. Participants visiting a peach palm plantation in Costa Rica during Latin American Regional Workshop in January 2002.

crop cultivars and soil conditions has led to an improved understanding of how soil testing laboratory and field personnel can jointly produce field- and crop-specific lime and nutrient recommendations that are far better than the "blanket recipes" currently used in most regions. With NuMaSS, we have found that field- and crop-specific software recommendations have greater sensitivity to producers' target yield goals and differences among soils and crop cultivars; this, in turn, leads to greater efficiency in lime/fertilizer usage and even savings in input costs. In many Latin American universities and technical schools, part of the curriculum on soil nutrient management for future agronomists and soil scientists now includes training on and problem solving with NuMaSS (Figure 3).

Training

Project collaborators have received extensive "on-site" training with NuMaSS, with the expectation that they serve as resource contacts for the software within their respective domains. We have also provided training to a total of 313 potential users via 10 software training workshops held in Mexico, Honduras, Nicaragua, Panama and Brazil during the six-year project (Figure 4). Workshops were organized and participants were selected by local collaborators, and included a mixture of researchers, extensionists, producers, students, consultants, fertilizer dealers and bank loan agents. Data produced via local project activities provided participants with locally-relevant examples for their "hands-on" practices with the software (Figure 5).

Figure 3. Ing. Benjamin Name of IDIAP-Panama giving a certificate and a copy of the NuMaSS software to a participant upon completion of the 2-day workshop held at Divisa, Panama in February 2005.

Software Distribution

In addition to software distribution to all participants of the training workshops, public access to the software has also been provided through download of a 32 Mb compressed file from a website (http://intdss.soil.ncsu.edu). During the nine months since the release of NuMaSS version 2.2, the software has been downloaded by 491 unique users from 37 countries in Latin America (92%), Africa (2%), Asia (2%), Europe (2%) and N. America (2%). In the early stages of this project and prior to the software's translation into Spanish and Portuguese, downloads were also available for NuMaSS interim versions 2.0 and 2.1. Of the 949 total downloads from the website, 81 percent were from 18 countries in Latin America. Interest in NuMaSS from Latin America clearly increased once the translated version (2.2) was available.

Figure 4. Dr. Manoel Cravo of EMBRAPA-CPATU explaining to participants of the NuMaSS workshop at Bragança, Pará, Brazil in August 2007 the differences between fertilizer and lime inputs/costs between cowpea plots receiving a NuMaSS recommendation (right) and one with the traditional inputs (left) used by farmers in the Tracuateua, Pará region.

Figure 5. Deanna Osmond (NCSU) assists participants from Nicaragua during the Honduras-Nicaragua workshop held in August 2002 at Siguatepeque, Honduras.

Sustaining Software Adoption

Collaborators have learned about field and laboratory methodologies both for testing original NuMaSS predictions and for acquiring pertinent crop and soil coefficients that will enhance the software's performance within user-specific regions. This will enable users to sustain software refinement, after project completion, as new crop varieties are introduced or their activities expand to new soil types within their regional domains.

Transparency in Fertilizer/Lime Recommendations

Traditional recommendations from laboratories and fertilizer dealers consist of specific quantities of lime and fertilizer nutrients or fertilizer mixtures; at best, these are supplemented with soil analytical results. The client, however, seldom has access to the information used to formulate the recommendations. These recommendations are often "blanket recipes" that might be based on marketing certain fertilizer mixtures and/or disregard differences in target yield levels, soil characteristics and even crops and their cultivars. NuMaSS empowers users to formulate their own lime/fertilizer recommendations from soil analytical results, exploring the potential outcomes for different types of available lime and nutrient sources, target yields, and differences among crops, cultivars and soils. Furthermore, the software enables an economic assessment of the lime and nutrient inputs; a favorable economic return might be assumed in traditional recommendations, but is seldom evident in their formulations.

Collaboration Between Soils Laboratories and Extensionists

A lot of the information used by NuMaSS (land use history, visual nutrient deficiency symptoms, indicator plants, target yield, crop cultivars) exceeds the information provided to laboratories for soil test analysis. NuMaSS enables field and laboratory agents to combine their information and produce collaborative results that are more beneficial to their clients. In regions where government-supported extension services have been downsized or eliminated, the NuMaSS tool facilitates researchers to fill the void in services to farmers.

Lime and Fertilizer Use Efficiency

In all the regions we have worked in Latin America, we have found that lime and nutrient use efficiency improves once the software's crop and soil coefficients have been adjusted to local domains. Various factors contribute to this improved efficiency: consideration of the target yield level, differences in crop/cultivar requirements and acidity tolerance, exclusion of nutrient inputs which are not limiting, and carry-over effects of legume N, P and lime to subsequent crops. In many instances we have convinced producers that their savings in inputs exceed the required cost of the soil test analysis for the software. In the sandy Ultisol regions of Northeast Pará, Brazil land use on about 30,000 ha has shifted from a single annual crop of cowpea to an 18-month intercropping system of cassava and three crops of a corn/rice-cowpea rotation. Cowpea yields have remained constant or increased and the only added inputs relative to the lime, P and K applied to the previous cowpea monoculture are 80-120 kg N/ha and 10-20 kg/ha.

Training Future Soil Scientists

Many of the universities in Latin America have incorporated NuMaSS into their courses related to soil nutrient management. Hopefully, this leads to a future cadre of soil scientists who are familiar and comfortable with the software's applications.

LESSONS LEARNED

Maintain a Program Structure that is Flexible in Accommodating Different User Interests

NuMaSS can do this because it encompasses the tropical regions globally and addresses 17 of the most common grain, tuber and forage crops grown therein. Initially, one needs to assess the existing knowledge base and institutional capabilities within the realm of soil nutrient management. This helps to identify information gaps, the potential for local adoption, and the nature of the tests that are needed within a given region (Figure 6).

Figure 6. Cheri Cahill (NCSU) and a collaborator from PROINPA are visiting a farmer near Toralapa, Bolivia to discuss they nutrient management strategies for potato and their crop rotation sequences between potato and faba bean.

Encourage Users to Think About How Their Local Soil Nutrient Management Experiences Fit into the Global Context

Most users have concentrated on addressing and solving the nutrient management issues within their specific domains. It takes some persistence to convince them to think about how their regional experiences and strategies compare to other regions. They become more receptive to the process of adopting a tool that is based on collective knowledge and experiences (Figure 7).

Figure 7. Differences in corn growth in the San Dionisio watershed of Nicaragua in 2006 between plots receiving little or no N fertilizer (yellow colors) and those with adequate N fertilizer inputs (dark green).

Identify the Decision Makers in Each Region for Nutrient Management

In some areas this might be the fertilizer dealers, whereas bank loan agents, researchers, extentionists or prominent farmers could play key roles in other areas. Successful adoption of NuMaSS needs to encompass exposure to and training with the software by the key decision makers in each region (Figure 8).

Figure 8. Dr. Jaime Salinas of INIFAP, Rio Bravo, Mexico introduces participants to the workshop objectives during the NuMaSS training workshop held in Reynosa, Mexico in February 2007.

NEXT STEPS

NuMaSS is not complete, because it fails to consider constraints by other essential nutrients such as K, S and micronutrients. Any of these additional nutrients, if limited in the soil, can prevent achievement of the targeted yield level with only lime and N and/or P inputs. Their exclusion from the software prevents a more detailed economic assessment of inputs to remedy the collective soil nutrient constraint in a given region.

Fertilizer dealers frequently point out that most of their sales entail mixtures or blends of N, P and K. Omission of a K component thus far for NuMaSS fails to properly account for the needs of this nutrient and its economic impacts. The potassium constraint is of widespread importance throughout the tropical regions but was not one of the five major constraints identified at the onset of this Grant. Hence, although frequently requested by our collaborators, funding for development of a K component required leveraging of resources from collaborating scientists involved with the SM CRSP.

Frequent requests have been made for the consideration of other commodities, particularly vegetables and perennial cash crops other than peach palm (coffee, banana, citrus, etc.). We excluded these crops during software development because their nutrient management information base was markedly less than that of the crops included in NuMaSS. Strategic research issues to fill existing knowledge gaps exceeded the available funding for software development.

Nevertheless, NuMaSS represents a software platform designed to fit user needs which has been tested and adopted by a variety of user conditions throughout tropical regions, and it intentionally has built-in flexibility for subsequent additions of other soil nutrient constraints and crops. The challenge to expanding NuMaSS to other crops and nutrients will be similar to the process used with soil acidity, N and P constraints; the identification of fundamental principles and development of rule sets that have global application to solving the nutrient problem at a field- and crop-specific level. The global aspects of the development process do not fit the regional interests of most potential donor groups, but are a good match with the CRSP's mandate to address strategic issues that are relevant throughout the world.

Marco Trejo (right) of CIAT-Honduras discusses with the farmer (left) potential outcomes of an on-farm N fertilization trial with corn at San Rafael, Nicaragua.

PARTICIPATING AND COLLABORATING SCIENTISTS & INSTITUTIONS/ORGANIZATIONS

National Agricultural Research Systems (NARS)

Bolivia

Instituto Boliviano Technologia Agropecuaria (IBTA-Chapare)
Armando Ferrufino

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

Brazil

Amazon National Research Institute
Charles Clement
Newton Falcão

Brazilian Agricultural Research Enterprise (EMBRAPA)
Edilson Brasil
Manoel Cravo
Oscar Lameira
Altevir Lopes
Manuel Macedo
Leo Miranda
Ronaldo Sarmanho
Austrelino Silveira
João de Souza

Milnio Farm, Tracuateua, Pará, Brazil
Benedito Dutra de Souza

University of Visçosa
Roberto Novais
Ivo Ribeiro da Silva

Costa Rica

Ministry of Agriculture
Antonio Bogantes

University of Costa Rica
Alfredo Alvarado
Danilo Alpizar
Jimmy Boniche
Gloria Melendez
Eloy Molina
Rafael Salas
Gabriela Soto

Ecuador

National Agricultural Research Institute (INIAP)
Soraya Alvarado
Francisco Mite
Franklin Valverde

Potash & Phosphate Institute (INPOFOS)
Jose Espinoza

Honduras

Agricultural Science and Technology Directorate (DICTA)
Oscar Cruz

Candelaria Community Technical Institute (ITC)
Juan López

Food and Agriculture Organization (FAO)
Edgardo Navarro

Honduran Agricultural Research Foundation—La Lima (FHIA)
Julio Herrera

National Agricultural University-Catacamas
Jose Reyes

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

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

International Center for Tropical Agriculture
Miguel Ayarza
Edwin Garcia
Pedro Pablo
Gilman Palma
Indipulati Rao
Carlos Rodrigues
Axel Schmidt
Marco Trejo

Mali

Institut d'Economie Rurale (IER)
Adama Bagayoko
Adama Coulibali
Birama Coulibali

Oumar Coulibali
Mamadou Diarra
Mamadou Doumbia
Hamidou Konare
Aminata Sidibe
Diakalia Sogodogo
Zoumana Kouyate

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

Nicaragua
National Institute for Agricultural Technology (INTA)
Reinaldo Navarete
Luis Urbina
Elbenes Vega

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

Philippines
Philippines Rice Research Institute
Miguel Aragon
Q. Asuncion
Madonna Casimero
R. Escabarte
H. Guines
Josephine Lasquite
B. Macarrubo
A. Mataia
Teodula Metra-Corton
Santiago Obien
J. Quinton

International Rice Research Institute
Thomas George

South Africa
Cedara Agricultural Research Station
Allan Manson

Thailand
Kasetsart University
Tasnee Attanandana

Togo
International Fertilizer Development Center
Tjark Bontkes
Charles Yamoah

United States
Colorado State University
Danna Hoag

Cornell University
David Bouldin
Danna Hoag
Shaw Reid

North Carolina State University
Sheri Cahill
Fred Cox
Denise Finney
Daniel Israel
Pedro Luna
Deanna Osmond
Frank Smith
Jot Smyth
Michael Wagger
Jeffrey White

Texas A&M University
Frank Hons
Lloyd Hossner
Anthony Juo
Hamid Shahandeh

University of Hawaii
Adrian Ares
Nguyen Hue
Richard Kablan
Hu Li
Russel Yost
Xinmin Wang

Private Sector
Understanding Systems, Inc.
Will Branch
Steve Pratt

TRAINING AND DEGREE PROGRAMS

Degree Programs

Year	Name	Degree	Gender	Institution	Home Country
2002	Yuji Nino	PhD	M	Texas A&M	Japan
2003	Jocelyn Bajita	PhD	F	Univ. of Hawaii	Philippines

Workshops

Title	Date	Location	Gender
Decision Processes for Determining Diagnostic & Predictive Criteria for Soil Management, PhilRice	Sept 6-10, 1999	Maligaya, Philippines	42M,5F
Latin American Regional Workshop	Jan 6-10, 2002	Guapiles, Costa Rica	18M,1F
Asian Regional Workshop	Jan 21-24, 2002	Maligaya, Philippines	14M,5F
African Regional Workshop	Mar 12-15, 2002	Lomé, Togo	22M,3F
Costa Rican Association of Soil Scientists	Aug 12-13, 2002	San Jose, Costa Rica	17M,5F
International Training Program on Integrated Soil Fertility Management	Oct 7-12, 2002	Lome,Togo	21M,1F
Honduras – Nicaragua Workshop	Aug 5-7, 2002	Siguatepeque, Honduras	17M,2F
National Inst. Agric. Tech.	July 21, 2003	Pergamino, Argentina	4M,4F
Panama Workshop	Feb 22-23, 2005	Divisa Panama	31M,5F
Honduras – Nicaragua Workshop	Mar 27-29, 2006	Siguatepeque, Honduras	18M
Mexico Workshop	Feb 24, 2007	Reynosa, Mexico	49M,2F
Brazil Workshhop	Aug 14-16, 2007	Braganca, Pará,Brazil	34M,7F
Nicaragua Workshop	Nov 26-27, 2007	Managua, Nicaragua	25M,2F
Honduras Workshop	Nov 29-30,2007	Siguatepeque, Honduras	29M,3F
Brazil Workshop	May 13-15, 2008	Paragominas, Pará, Brazil	28M,6F
Brazil Workshop	May 20-21, 2008	Belém, Pará, Brazil	40M,6F

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Molina, E., A. Alvarado, T.J. Smyth, J. Boniche, D. Alpizar and D. Osmond. 2002. Response of heart-of-palm from peach palm (Bactris gasipaes) to nitrogen in Costa Rican Andisols. Agronomia Costarricense 26:31-42. (In Spanish)

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Mr. Reinaldo Navarrete (right) of INTA, Nicaragua and Mr. Santos Chavarria (left) of San Rafael, Nicaragua present the results in March 2007 for the corn field trial on Mr. Chavarria's farm comparing local practices and NuMaSS recommended fertilization to the other collaborators who conducted similar on-farm trials in different regions of Honduras and Nicaragua.

Chapter Three

Tradeoff Analysis

SCALING UP AND TECHNOLOGY TRANSFER TO ADDRESS POVERTY, FOOD SECURITY AND SUSTAINABILITY OF THE AGROENVIRONMENT

JOHN M. ANTLE, DEPARTMENT OF AGRICULTURAL ECONOMICS AND ECONOMICS
MONTANA STATE UNIVERSITY, BOZEMAN, MT, USA

MONTANA STATE UNIVERSITY

Farmers preparing the upland fields in the Pallisa District in southeastern Uganda.

Table of Contents

Tradeoff Analysis – Montana State University

OVERVIEW & EXECUTIVE SUMMARY

The Tradeoffs Project's long-term goal was to develop a method (Tradeoff Analysis) and tools (the Tradeoff Analysis software) to enable research teams to provide information to support informed policy decision making that involves agricultural systems. Tradeoff Analysis is a participatory process designed to bring together public and private stakeholders with research teams to identify key sustainability indicators that are used to characterize tradeoffs in the system of interest. The stakeholders also help identify key scenarios for improvement of the system. The Tradeoff Analysis software is a tool that the research teams can use to implement quantitative, ex ante assessment of the proposed scenarios, using site-specific data and appropriate disciplinary models of crop growth, economic decision making, and environmental processes. Various tools, including graphs and maps, can be used to communicate findings to stakeholders.

Phase I of the Tradeoffs Project involved development of the methods and tools, and their preliminary implementation, primarily in case studies in Ecuador and Peru. Phase 2 involved further development of tools, implementation of new case studies in East and West Africa, and dissemination through a series of training workshops in Latin America, East Africa and West Africa. In addition, the Tradeoff Analysis methods were extended to address scaling up applications, and to facilitate analysis of poverty and sustainability, including analysis of ecosystem service supply, such as carbon sequestration, watershed management, and biodiversity conservation. A new "Minimum Data" modeling approach was developed and disseminated, in response to the perceived limitations of complex, data-intensive modeling tools. In addition, the case studies in Latin America and East and West Africa were utilized to carry out assessment of impacts of climate change in these systems. At the end of Phase 2, a new 3-year, $1.5 million project using the Tradeoffs method and tools, on agricultural adaptation in East Africa, was funded by the German Development Agency, and ICARDA and ICRISAT adopted the Minimum Data approach for use in a new 3-year, $500,000 USAID-funded project on dryland desertification (Oasis).

The objectives of the Tradeoffs Project in Phase 2 were to further develop the Tradeoff Analysis methods and modeling tools developed in Phase I, and to transfer the use of these methods and tools to collaborating institutions to address poverty, food security and sustainability of the agro-environment.

Objectives for Phase 2 were:

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.
2. Develop Methods to Scale-up the Analysis Possible with the TOA Method from Single Agro-ecozones (e.g., Watershed Scale) to Larger Regional (Sub-national or National) Scales.
3. Development of Protocols and Materials to Transfer the TOA Method and the TOA Model Software to Existing and Future User Groups.

All of these objectives were accomplished during Phase 2, as described below.

PHASE 2 PROJECT ACCOMPLISHMENTS

Objective 1: Further Develop and Refine TOA Methods and Models

A major goal of the Tradeoff Project for Phase 2 was to further develop and test the TOA approach and tools through new applications with collaborating institutions. To facilitate this process, the TOA team developed demonstration applications for collaborators:

Senegal Peanut Basin

In collaboration with the Senegal Agricultural Research Institute, the Ecole National de Economie Applique (National School of Applied Economics) (ENEA), and the Peanut CRSP, the Tradeoffs project acquired and digitized data collected by ENEA in 2000-2004 in this region (the major agricultural region of Senegal). In addition, the Tradeoffs Project conducted its own surveys in the region. In collaboration with the Bureau of Macroeconomic Analysis (BAME) in Institut Sénégalais de Recherches de Agricoles (ISRA), these data were assembled and used to parameterize models for Tradeoff Analysis of policy and technology options. These data and models were used as the basis for the training workshop held in Dakar at ENEA in 2003. In July 2007 a national stakeholder workshop was held at ISRA in Dakar where BAME researchers presented analysis results. Various publications resulted from this application (Antle and Stoorvogel 2007, 2008; Antle et al. 2007; Diagana et al. 2007; Gray 2005; Kempen 2005; Niang 2004; Stoorvogel et al. 2008.)

Machakos Region of Kenya

In collaboration with the Kenya Agricultural Research Institute and the Dutch Agricultural Economics Institute program on Nutrient Monitoring, the Tradeoffs team developed a Tradeoff Analysis application for this important region of Kenya and used it as the basis for a TOA training workshop in Nairobi in 2004. The Machakos model was also used as the basis for analysis of climate change impacts and analysis of soil carbon sequestration. Various publications resulted from these activities (Antle et al. 2005; Antle and Stoorvogel 2007, 2008; Antle and Valdivia 2008; Ellenkamp 2004; Mora-Vallejo et al. 2007a, 2007b, 2007c; Stoorvogel, Antle and Valdivia 2008).

Pallisa District, Uganda

A team of scientists from Makerere University, Uganda, was trained at the TOA workshop in Nairobi in 2004. Subsequently, a collaboration with Makerere University was co-funded by the TOA project and by the FAO project on Ecosystem Services and Poverty. Data from the WUR WUR (Wageningen University Research Center) Nutrient Monitoring program were utilized to conduct a preliminary analysis of the use of ecosystem services to address wetlands protection in the region. One publication resulted from this work (Nalukenge, Antle and Stoorvogel, 2008).

Wa District, Northern Ghana

In collaboration with the Sahel Agriculture Research Institute and the University of Florida SM CRSP project, a "Minimum Data" analysis of soil carbon sequestration was implemented. Training to Ghanian collaborators was provided at a workshop in 2006.

Panama

In collaboration with the Panamanian Agricultural Research Institute and the International Potato Center, a research team was trained in the use of the Minimum Data analysis. It was used to study pesticide use in potato systems.

Altiplano of Peru

Researchers at the International Potato Center were trained in use of the Minimum Data analysis, and it was applied in a study of biodiversity preservation in the Altiplano region.

Northern Plains, United States

In collaboration with the Agricultural Research Service of USDA in Mandan, ND, the Minimum Data modeling approach was used to study carbon sequestration and biofuels production potential. A paper was presented at an international conference based on this work (Antle, Archer and Hanson 2007).

In summary, the project objective of disseminating the TOA methods and models was accomplished, and training was provided to about 100 researchers in East and West Africa, Latin America, and the United States (see project statistics for further details). In addition, the TOA software was available for downloading from the project web site. The software was downloaded by over 60 researchers in 28 countries.

Objective 2. Develop Methods to Scaleup the Analysis Possible with the TOA Tools

Several strategies were investigated for scaling up TOA analysis:

- Use of aggregate data
- Fractal methods
- Extrapolation of case studies to larger regions
- Adaptation of existing survey designs to TOA
- Using secondary data and simplified modeling designs ("minimum data approach")

The last two options were found to be most viable. Research in collaboration with ISRA and ENEA in Senegal resulted in procedures to combine existing survey data for use in TOA modeling. Collaboration with Wageningen University and the Dutch Agricultural Economics Institute developed methods to utilize the Nutrient Monitoring system data from East Africa for TOA analysis (the Nutrient Monitoring (NUTMON) system is a computerized system for farm data collection and analysis of nutrient balances). This approach was used to develop TOA applications in Kenya and Uganda.

In addition, to overcome the high data demands of TOA models, a new "Minimum Data" (MD) approach was developed. This approach was designed to allow implementation of economic models using existing secondary data (e.g., average yields and costs of production, and measures of spatial variability in yields and costs) rather than requiring extensive farm survey data. MD methods for crop models and environmental process models were also investigated. The methodology underlying this approach was published in 2006, and four applications of the MD approach were subsequently published in 2007 and 2008. In addition, a new project on adaptation to climate change was funded by the German Development Agency (GTZ) to begin in 2008, and the approach was adopted for use in a USAID-funded project led by ICARDA and ICRISAT in 2008.

Another significant development was in the area of methods to link TOA to market models. Methods to link TOA analysis with market-equilibrium models were developed and incorporated into Roberto Valdivia's PhD research. The TOA software was modified to implement the market equilibrium analysis, and supplementary software was developed for model simulation in the SAS language.

Analysis of climate change impacts and adaptation was another area in which research was developed so that the TOA modeling system could be used. The case studies in Kenya, Peru and Senegal were used for this purpose. Results from IPCC climate simulation scenarios were linked to these case studies by downscaling the Global Circulation Model (GCM) data. Analysis of climate impacts was carried out with seven GCMs to investigate sensitivity to alternative climate models and scenarios.

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

A variety of activities were carried out:

- Jetse Stoorvogel of WUR created a web site for the TOA Model (www.tradeoffs.nl) with on-line training materials in PY6. The TOA model, sample programs, and workshop materials can be downloaded from this web site. These materials formed the basis for the Senegal workshop and were revised and used for the workshops in Kenya and Panama.
- Through Phase 2 experiences developing new collaborations, a process for transferring the TOA method and tools to clients was established. This process involves training workshops with collaborators who have data for an application, and a process of follow-up to provide technical support and interpretation of results.
- Procedures for linking data collected with the Nutrient Monitoring system to TOA analysis were developed in Year 7. This linkage will be used to expand the general applicability of the TOA method and software and to develop further collaborations in the East Africa region and elsewhere in the world that the NUTMON methodology has been applied.
- The TOA on-line course was adapted to the minimum data methodology. These materials are available on-line at the project web site and have been downloaded by over 100 users.
- Antle and Stoorvogel developed a PhD-level course on TOA modeling and taught the course Spring quarter 2006 at UC Davis. The course materials are available on-line. A similar course will be taught at Oregon State University by Antle beginning in 2009.

HIGHLIGHT OF ACCOMPLISHMENTS: TRADEOFF ANALYSIS WORKSHOP ON PAYMENTS FOR ENVIRONMENTAL SERVICES, PALLISA, UGANDA

On March 8, 2006, the TOA Project organized a workshop in collaboration with Makerere University at Pallisa Country Inn in southeastern Uganda. This workshop was cofunded by the TOA Project and the Food and Agriculture Organization project on Payments for Environmental Services.

The objective of this workshop was to consult the various stakeholders involved in the management of agro-ecosystems about the feasibility of adoption of the Payments for Environmental Services (PES) as an alternative to conventional agricultural and environmental policy tools to curb ecological degradation in Pallisa district (Figures 1, 2, 3). PES involves providing payments directly to farmers who adopt practices that increase the environmental services that flow from the land the farmer manages. Pallisa is one

Figure 1.View of upland and lowland fields in the Pallisa District. (Photo: J. Antle)

of those Uganda's districts where excessive environmental degradation has taken place due to extensive economic activities. Currently, about 68 percent of the existing wetland area has undergone extensive reclamation to open up land for rice growing and other agricultural activities. Experience from other parts of the world shows that PES can motivate farmers to increase the supply of environmental services from agricultural lands by changing management practices appropriately. The feasibility of this approach under Ugandan conditions is being researched through a collaboration between Makerere University, Montana State University and Wageningen University, with funding from the Food and Agricultural Organization of the United Nations (FAO) and the U.S. Agency for International Development (USAID). This collaboration is investigating the feasibility of PES in agriculture and its impact on poverty reduction among Ugandan farmers. The stakeholders that participated in the workshop are farmers, non-governmental organizations, community-based organizations, policy makers, local government representatives, and scientists. The institutions from where participants were drawn and their affiliations are documented in Appendix I.

The workshop program (Appendix II) included presentations by the TOA team on the TOA approach, followed by presentations on issues by stakeholders, breakout groups to assess indicators and scenarios, and a concluding session that summarized results from the breakout groups.

After the morning presentations (Figures 4 and 5), the participants were split into three breakout groups to discuss issues regarding the current status of the wetlands, the main indicators describing this status, possible scenarios for change and the feasibility of payments for environmental services (Figure 6). The following questions were given to the breakout groups for discussion. A summary of the responses from the breakout groups follows each question.

Note: The participants decided the first two questions were answered in the presentations and so did not discuss them in the breakout groups.

1. What are the main reasons to conserve or not conserve the wetlands?

2. Who owns the wetlands? Are there conflicts with use of the wetlands?

3. What are appropriate sustainability indicators for the wetland agro-ecosystem?

- Economic and social indicators:
- Agricultural productivity
- Agricultural production
- Income
- Food security
- Poverty
- Conflicts over use
- Soil productivity/degradation

- Environmental indicators:
- Water quality (eutrophication, contamination, sedimentation)
- Water quantity (less water in boreholes (wells))
- Biodiversity (fish, birds, plants)
- Micro-climate

Figure 2. View of Lake Kyoga in Pallisa District.

Figure 3. Farmers preparing the upland fields. (Photo: J. Antle)

- Health indicators
• Malaria
• Malnutrition
• Bilharzia (more snails)

4. Using these indicators, what do you think is happening to the agro-ecosystem?
The participants generally agreed that all of the indicators are worsening.

5. What can be done to improve those indicators that are worsening (scenarios)?
• Create awareness and provide training on improved soil and water conservation (for both uplands and lowlands).
• Restoration of wetlands and water catchments (e.g., agro-forestry).
• Improved access and affordability of fertilizers.
• Establishing cover crops and green manure.
• Training and involving communities in the development of environmental action plans.
• Enact environmental bylaws (and enforcement) by local governments.
• Encourage fish farming.
• Promote IPM (Integrated Pest Management).
• Proper disposal of waste.
• Improved rice varieties for uplands.
• Improved markets for produce.

6. What organizations could implement payments for environmental services (communities, government, non-government, micro-credit)?
All participants agreed that the organizational structure should be a combination of CBOs (Community Based Organizations), NGOs (Non-Governmental Organizations) and local governments. One group suggested including special interest groups, specifically focused on wetlands management. A general remark was that the implementation should be consistent with environmental laws and policies at the national level. There was also concern that political interference could hamper attempts to reduce encroachment in the wetlands.

Figure 4. Imelda Nalukenge of Makerere University introducing the project to workshop participants. (Photo: J. Stoorvogel)

This workshop was highly successful on several fronts. First, it provided an informative overview of the issues related to wetlands management in the Pallisa region, from the perspective of the local stakeholders and in terms of na-

*Figure 5. Wilson Okiror presenting the major farming systems of Uganda to workshop participants. (*Photo: J. Stoorvogel*)*

Figure 6. Group discussions of Indicators, Tradeoffs and Scenarios. (Photos: J. Stoorvogel)

tional policy. The workshop presentations and discussions made clear that while national policy has established wetland areas as public lands to be managed in the public interest, local people have long used the wetlands and are continuing to use them to meet their needs for subsistence and for production of livestock and crops, particularly rice. While this use of the wetlands is helping rural households to meet their immediate needs, there was a consensus among workshop participants that agricultural use of the wetlands was leading to potentially significant degradation of water quantity and quality which in turn has other adverse environmental effects.

A major conclusion that the research team took from the workshop was that the present system of national environmental laws was not successful in achieving protection of the wetlands. A key reason for this failure was that the current approach was based on regulations that tend to lead to conflicts between local people and the regulatory agency, NEMA, and its local representatives. These regulations are difficult to enforce, and the resulting open-access utilization of the wetlands is leading to a classic "tragedy of the commons" outcome.

Under these circumstances, payments for environmental services (PES) may indeed provide a viable alternative approach to protecting wetlands areas. There are two key challenges to implementing a PES system. First, the wetland services must be identified and quantified, and the economic feasibility and institutional feasibility of implementing PES must be assessed. The workshop provided a list of services that local stakeholders value, and this list needs to be supplemented with other scientific information, such as the extent of wetlands utilization for agriculture and other activities. Second, the question of who would pay for the environmental services must be addressed. The beneficiaries would range from local people and communities, to national policy organizations (e.g., NEMA) that represent the national interest, to people downstream in other countries in the Nile watershed, to global organizations and individuals interested in environmental conservation.

The current research project, co-sponsored by the USAID Soil Management CRSP Tradeoffs Project, and the FAO Payments for Environmental Services Project, will be exploring the first of these two questions, i.e., the economic and institutional feasibility of PES in the Pallisa region. The findings of that work were presented at a national workshop in September 2008.

Figure 7. Group participants.

LESSONS LEARNED

A major lesson learned from the experiences of the Tradeoffs Project concerns the type of modeling tools that are useful to stakeholders at national and international research and policy institutions, with the goal of providing information that is useful to researchers and policy decision makers on ex ante research impacts of technologies and to policies. Most modeling tools that are developed by researchers are research tools that require extensive training and large amounts of data. The Tradeoff Project also developed this type of modeling tools, the Tradeoff Analysis Software. While this software development was successful, and produced research results that were widely published in professional journals, it can only be used by a team of highly specialized researchers with adequate data and time to invest in model development. As a result, adoption of the TOA software by other researchers was limited. In contrast, the "minimum data" (MD) modeling approach developed by this project was highly successful in the sense that it was adopted for use by a relatively large number of researchers at both national and international institutions. The MD approach requires only a few days training to be used by researchers with a Master's degree level of understanding of economics and agricultural systems science, and can be implemented with relative simple secondary data typically available to researchers in most countries. The MD approach was highly successful, with researchers at both national and international research institutions being able to use it with relatively minimal training.

The key lesson learned from this experience is that researchers need to carefully re-assess the strategies they use to develop data and tools intended to be used by other researchers and policy analysts. Data and tools designed to be used for academic research are not likely to be used by applied agricultural researchers or policy analysts. However, this does not mean applied researchers and policy analysts do not want or need quantitative tools. Rather, the lesson learned is that these potential users need tools that are compatible with the data, time and financial resources they that they have, to help them make more informed decision.

NEXT STEPS

The TOA project team prepared a proposal to the German Development Agency (GTZ) in late 2007 to fund a project using TOA methods to assess adaptation to climate change in East African agriculture, in collaboration with the International Potato Center. This project was funded for three years with a budget of EU 1.15 million and began work in May 2008. Additionally, in 2008 the TOA team was asked to provide training to a USAID-funded project managed by ICARDA and ICRISAT on assessment of technologies for dryland areas. A training workshop will be held in Nairobi in September 2008 to train interdisciplinary teams from ICARDA, ICRISAT, and national research institutions from Kenya, Ethiopia, Uganda, Morocco, Algeria, Yemen and Syria. TOA-related research and training will be continued through the collaborative work of Oregon State University and Wageningen University.

APPENDIX I: LIST OF WORKSHOP PARTICIPANTS

Name	Institution	Designation/position
1.Mr. George Lubega Matovu	National Environmental Management Authority (NEMA)	Natural Resource Management Specialist
2. Mr. Wilson Okiror	Farmer	Farmer trainer
3. Mr. Oba Ebaait Peter	ECOTRUST	CBO Representative
4. Mr. Egutu Vincent	Farmer	Farmer
5. Prof. John Antle	Montana State University, U.S.A	Professor
6. Ms. Nakende Kizire	Farmer	Farmer trainer
7. Mr. Oonyu Robert	MORUKOKURE (CBO)	Agro forestry Coordinator
8. Prof. Jetse Stoorvogel	Wageningen University of Research	Professor
9. Dr. Jenipher Bisikwa	Makerere University, Kampala	Lecturer/Scientist
10. Mr. Nyiro Julius	Local Government	Agricultural Officer
11. Ms. Berna Nyamurura	Farmer	Farmer
12. Mr. Okozoi Joseph	Local Government	Agricultural Officer
13. Dr. Imelda Nalukenge	Makerere University, Kampala	Lecturer/Scientist
14. Dr. Lukman Mulumba	National Agricultural Research Organization NARO	Senior Research Officer
15. Mr. Nsekere Musa	Tweweyo	Chairperson
16. Mrs. Musana Sarah	Tuganike Women Association	Chairperson
17. Mr. Walyaba Samuel	MAYODEF	Coordinator
18. Dr. Gabriel Elepu	Makerere University, Kampala	Lecturer/Scientist
20. Mr. Kedi John	Agule United Farmers' Association	Coordinator
21. Mr. Wachira Kanguongo	International Potato Center Nairobi	Research Officer/Scientist
22. Dr. Lieven Classens	International Potato Center Nairobi	Research Officer/Scientist
23. Mr. Yashin	Makerere University, Kampala	MSc. Student
24. Mr. Feraalo Willy	Pallisa District Environment Forum	Coordinator
25. Mr. Ochenget Robert	PACONET	Coordinator
26. Mr. Muhoga Patrick	Pallisa District Local Government	Pallisa District Production Officer
27. Mr. Samuka Mohamed	Pallisa District Local Government	District Environmental Officer
28. Ms. Icheduna Christine	Pallisa District Local Government	District Agricultural Officer
29. Mr. Moses Lubinga	Makerere University, Kampala	MSc. Student

APPENDIX II: WORKSHOP PROGRAM

Venue: Pallisa Country Inn

8.30AM	Arrival and registration of participant	Moses Lubinga (Makerere University)
8.45AM:	Introductions	Imelda Nalukenge
9.00AM:	Introduction to MU/MSU/FAO project	Imelda Nalukenge
9.30AM:	Payments for Environmental Services	Prof. John Antle Montana State University, U.S.A
10.00AM:	Tradeoff Analysis	Professor Jetse Stoorvoge Wageningen University, Netherlands
10.30AM	Break Tea	
11.00AM:	Environmental laws and policy concerns in Pallisa District	Mr.George Lubega, NEMA Mr. Mohamed Samuka, Pallisa District Environmental Officer
11.30AM:	Role of NGOs/Community-Based Organizations in environmental protection programs in Pallisa District	ECOTRUST representative
12.00 PM:	Farming systems in Pallisa District & extent of environmental protection activities carried out among farming communities	Mr. Okiror Wilson
12.30PM:	Lunch	
1.30PM:	Introduction to group discussions	Lieven Claessens, CIP
1.45PM:	Group Discussions	
3.00PM:	Reports from workgroups	
4.00PM:	Wrap-up discussions	John Antle/Jetse Stoorvogel
4.30PM:	END	

PARTICIPATING AND COLLABORATING SCIENTISTS & INSTITUTIONS/ORGANIZATIONS

National Agricultural Research Systems (NARS)

Canada

University of Toronto
D. Cole

Ecuador

Inst. Nacional de Inestigationes Agro-Pecuarias
Victor Barrera
J. Cordova

Pontifica Univ. Catolica
R. Merino

Kenya

Kenya Agricultural Research Institute (KARI)
P. Gicheru

Netherlands

Research Institute for Agrobiology and Soil Fertility (AB-DLO)
A Havercort
R. van Haren

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

Panama

Inst. De Investigaciones Agro-Pecuarias
M. Sarmiento

Peru

Instituto Nacional de Investigaciones Agrarias
H. Cabrera

Univ. Nacional Cajamarca
P. Muck

Senegal

Ecole National d'Economie Applique (ENEA)
I. Hathie

Institut Sénégalais de Recherches Agricoles (ISRA)
A. Dieng
A. Fall
A. Mankor

United States

Montana State University
John Antle

University of Florida
James W. Jones

Uganda

Makerere University
Imelda Nakulenge

International Agricultural Research Center (IARC)

International Potato Center (CIP)

S. Sherwood (Ecuador)
P. Espinosa (Ecuador)
L. Claessens (Kenya
C. Crissman (Ecuador)
G. Forbes (Ecuador)
W.Kaguongo (Kenya)
R. Quiroz (Peru)
M. Tapia (Peru)

TRAINING AND DEGREE PROGRAMS

Degree Programs

Year	Name	Degree	Gender	Institution	Home Country
2004	Abibou Niang	MS	M	Wageningen Univ & Res Cntr	Senegal
2004	Roberto Valdivia	MS	M	Montana State Univ	USA
2005	Cecilia Romero	PhD	F	Wageningen Univ & Res Cntr	Peru
2005	Guillermo Baigorria	PhD	M	Wageningen Univ & Res Cntr	Peru

Year	Name	Degree	Gender	Institution	Home Country
2005	Kara Gray	MS	F	Montana State Univ	USA
2005	Reinier Ellenkamp	MS	M	Wageningen Univ & Res Cntr	Netherlands
2005	Renzo Barron	MS	M	National Agrarian Univ, La Molina	Peru
2006	Denis Arica	MS	M	National Agrarian Univ, La Molina	Peru
2008	Alejandra Mora-Vallejo	PhD	M	Wageningen Univ & Res Cntr	Chile

Workshops

Title	Date	Location	Gender
Tradeoff Analysis	2003	Dakar, Senegal	18M,3F
Tradeoff Analysis	Sept. 2004	Nairobi, Kenya	14M,8F
Tradeoff Analysis	Feb. 2005	Panama City,Panama	5M,1F
Carbon-Tradeoff Analysis	Mar. 2-3, 2006	Accra, Ghana	18M,1F
Payments for Ecosystem Services	Mar. 8, 2006	Pallisa, Uganda	20M,5F

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Chapter Four

Rice-Wheat Systems

ENHANCING TECHNOLOGY ADOPTION FOR THE RICE-WHEAT CROPPING SYSTEMS OF THE INDO-GANGETIC PLAINS

JOHN M. DUXBURY, DEPARTMENT OF CROP AND SOIL SCIENCES
CORNELL UNIVERSITY, ITHACA, NY, USA

JULIE G. LAUREN, DEPARTMENT OF CROP AND SOIL SCIENCES
CORNELL UNIVERSITY, ITHACA, NY, USA

CORNELL UNIVERSITY

A close up of rice on permanent beds.
(Photo: A.S.M.H.M. Talukder)

Table of Contents

Rice-Wheat Systems – Cornell University

OVERVIEW & EXECUTIVE SUMMARY

This report summarizes eleven years of research by Cornell University under the SM CRSP, focusing on one of the world's major food production systems, the rice-wheat cropping system of the Indo Gangetic Plain (IGP) region of Pakistan, India, Nepal and Bangladesh. With deep alluvial soils and widespread access to irrigation, agriculture in the IGP is not the risky venture that it is in many developing countries. Nevertheless, it is widely recognized that the productivity of the rice-wheat cropping system is stagnating and possibly declining. The reasons for this are not well understood, but various biotic and abiotic constraints have been suggested. Additionally, emphasis on cereal production and inadequate diversity in agricultural production has come at the cost of increasing micronutrient malnutrition in the South Asian populous. A combination of government policies, poor soil physical and chemical conditions and lack of improved varieties has hindered the production of grain legumes which were the traditional sources of key micronutrients for humans.

During Phase 1 of our program (1997-2002) we concentrated on diagnosing major constraints to crop productivity in the rice-wheat system, undertaking research to better understand these constraints, and identifying/developing soil management practices to improve food and nutritional outputs, natural resource quality and agricultural sustainability. The work was done primarily in Nepal and Bangladesh because of sanctions imposed by the U.S. government against India and Pakistan in 1998. In Phase 2 (2002-2008), key Phase 1 technologies/practices developed for improved crop production were utilized to develop methods to accelerate technology dissemination and scaling up of soil management practices from local to regional and national scales. In 2005, our technology dissemination work was scaled up beyond the IGP in order to address similar root health problems for rice in the sandy, low fertility soils of Northeast Thailand.

In Phase I:

1. We determined that poor root health is the major constraint to increasing crop productivity in the rice-wheat system, especially for rice. Diagnostic research with soil solarization showed that poor root health caused by soil-borne pathogens can reduce rice yields by 20-50 percent. The "Healthy Seedlings Technology" which involves solarization of rice nursery soils was developed to provide a simple soil treatment for resource poor farmers to address nematode and pathogen problems in flooded rice. Enriching rice and wheat seed with micronutrients (see below) also helped plants to resist soil borne pathogens or improve tolerance to infection.
2. The project documented that alternative soil and crop management practices to address soil physical constraints led to higher productivity, crop diversification and input/natural resource savings compared to conventional practices. For example increased grain yields of rice, wheat and mungbean were achieved with permanent raised beds on three soil texture types. Beds reduced water use in all crops, reduced seed/seedling rates, and improved fertilizer N response in rice. Direct seeding of rice coupled with surface seeding of wheat for heavy textured soils gave higher system grain yields than conventional practice while saving time, labor, water and rebuilding soil carbon. Surface seeding of rice and wheat also was successful on lighter textured soils, giving a no-equipment, no-tillage option for small farmers. Yield of surface seeded wheat was increased 35-70 percent by using mulch to aid stand establishment, conserve water, and suppress weeds. Rice yield was increased 15 percent with mulch, possibly due to reduced ammonia-N volatilization from the paddy.
3. Micronutrient enriched rice and wheat seed, generated by foliar or soil fertilization of mother plants, overcomes widespread soil micronutrient deficiencies (Zn, Mo, Cu), helps seedlings resist soil borne pathogens and increases yields by up to 40 percent. This research also established that some of the new rice and wheat lines released by Bangladesh and Nepal national breeding programs were particularly susceptible to Zn, Mo or B soil deficiencies. Breeders are now screening pipeline and released wheat germplasm for tolerance to sterility caused by B deficiency. However, similar programs to assess genetic susceptibility of rice and wheat to Zn or Mo soil deficiencies are still needed. Basic research in Nepal tested soil fertilization and micronutrient seed priming methods for improving Zn, B and Mo nutrition of grain legumes. Micronutrient seed priming involves soaking seeds in a micronutrient solution prior to sowing. The results formed the basis for the Mo seed priming technology, which has

alleviateds severe nitrogen deficiencies of grain legumes grown on Mo deficient acid soils in eastern India, Nepal and Northwest Bangladesh.

4. We documented that a single application of 1-2 t/ha of lime produced average yield benefits of 0.5 t/ha and 0.75 t/ha, respectively over 4-5 sequential crops of rice and wheat on acid soils in Bangladesh. This basic research combined with recent commercial efforts to import lime from Bhutan and increasing expansion of maize cultivation in the acid soil areas of Bangladesh justified developing lime recommendations for a national lime program which was implemented during Phase 2.

Objectives for Phase 2 were:

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.
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.

PHASE 2 PROJECT ACCOMPLISHMENTS

1. The project disseminated the Healthy Seedlings Technology to 15,000-18,000 farmers to address root health problems for rice and vegetable production in Bangladesh, Nepal and Thailand. This was achieved by promoting linkages between NARS with technical knowledge and technology transfer agents such as NGOs, private sector associations and national agricultural extension systems. We documented moderate (25-40 percent) to high adoption (65-80 percent) of healthy seedlings, together with excellent productivity increases and large economic benefits to households and the commercial sector. Knowledge support networks of national agricultural research scientists, extension officers and private sector associations (seed companies, input suppliers, commercial nurseries) were established to provide trained, sustainable support for technology dissemination, backstopping and scaling up beyond the life of the project. Informational and promotional materials were developed and distributed for radio, TV, the internet, national extension programs, NGOs and agro-input supply shops.
2. The permanent raised beds practice was successfully disseminated in Natore, Bangladesh utilizing existing farmer community groups to promote, train and encourage participatory testing of the new practice. Enthusiasm for the technology grew quickly because of increased rice and wheat yields; opportunities for crop diversification; improved natural resource management and positive economic impacts. Farmer-to-farmer transfer through hands-on equipment trainings, group sharing, farmer advocates, participatory testing and sustained technical backstopping from national agricultural research scientists were key factors that accelerated adoption of this technology.
3. We developed the chemical basis for lime recommendations of acidic soils in Bangladesh by comparing NuMaSS, SMP buffer and calcium carbonate incubation method predictions in field experiments at six sites in four districts of NW Bangladesh. From the results, a white paper, which summarized yield and economic benefits and required agricultural lime imports for a national lime program, was prepared and submitted to the Bangladesh Agricultural Research Council and Bangladesh Department of Agricultural. A map of lime requirements was developed and incorporated into the Bangladesh Country Almanac, a USAID funded spatial database tool for characterizing agriculture and natural resources in the country (USAID Bangladesh Mission funding to CIMMYT 2002-2006).

HIGHLIGHTS OF ACCOMPLISHMENTS

Root Health Constraints and the Healthy Seedlings Technology

Soil solarization is a method for *in-situ* solar pasteurization of soil and is used worldwide as an alternative to fumiga-

Figure 1. Soil solarization diagnostic plots. (Photos: J. Duxbury)

Figure 2. Root knot nematode (Meloidogyne graminicola) galls on rice. (Photos: J. Duxbury)

tion for commercial vegetable and fruit cultivation. We used soil solarization as a diagnostic tool (Figure 1) at 48 sites across Bangladesh and Nepal to evaluate the extent and importance of soil borne pests and diseases as potential constraints to rice and wheat production.

Yields of wheat increased on average 0.67 t/ha with solarization, while average rice yields increased by 0.83 t/ha. Focused studies to determine the specific constraints overcome by solarization indicated that rice root knot nematode (Meloidogyne graminicola, Figure 2) and a complex of other soil borne pathogens (Pythium, Rhizoctonia, Helminthosporium, Bipolaris sorokiana) were dominant. Subsequent surveys of farmer rice nurseries in Nepal and Bangladesh (Figure 3) and northeast Thailand indicated that root health problems were extensive, thus confirming that soil borne pathogens are the major constraint to increasing production in the rice-wheat cropping system.

The Healthy Seedlings Technology (HST) was developed as a simple, low cost, non-chemical soil treatment to address pathogen pressures on rice. Rice seedlings from solarized nurseries were substantially taller than seedlings from unsolarized nurseries while the roots were bigger, lighter in color and had less pathogen damage (Figure 4). During initial testing, a majority of farmers comparing HST with conventional practice obtained rice yield increases greater than 20 percent and averaging 1.2 t/ha.

Figure 4. Comparison of normal and HST rice seedlings from farmer nurseries; normal seedlings on left, HST seedlings on the right of each panel. (Photos: K. Lendup; R. Khanal)

Technology dissemination of HST was accomplished by linking research scientists from Nepal Agricultural Research Council and Bangladesh Agricultural Research Institute with technology transfer partners. Initially we

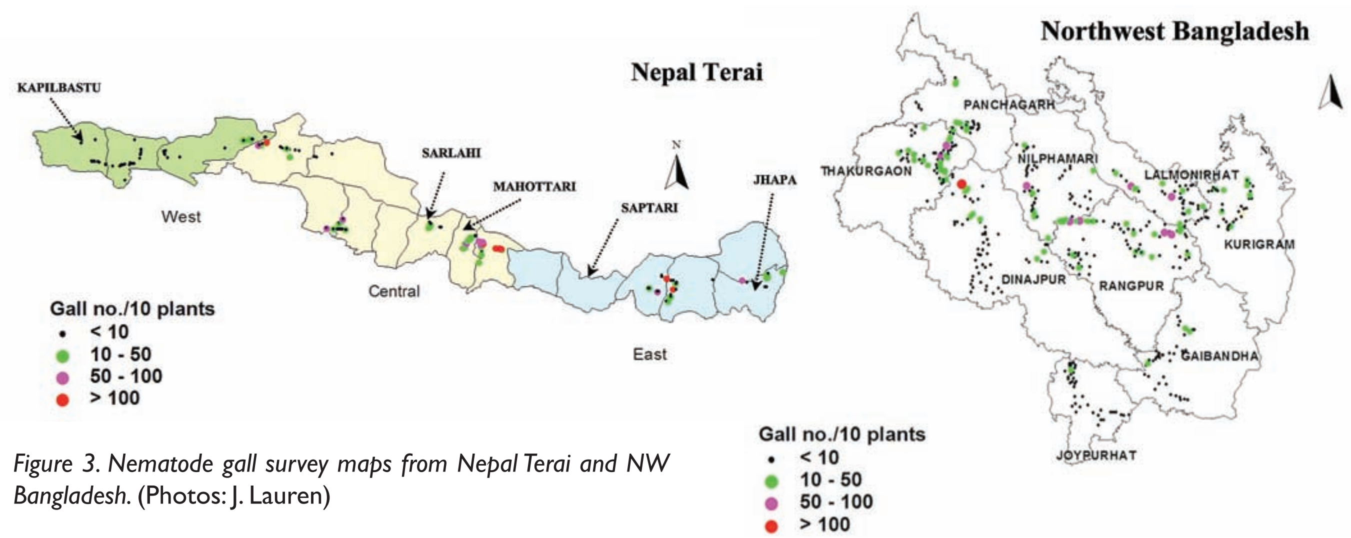

Figure 3. Nematode gall survey maps from Nepal Terai and NW Bangladesh. (Photos: J. Lauren)

Figure 5. Examples of farmers training on HST in Nepal. (Photos: C. Adhikari)

collaborated with large international NGOs CARE (Bangladesh, Nepal) and Winrock, national NGOs Rangpur Dinajpur Rural Service (RDRS) and Bangladesh Rural Advancement Committee (BRAC), several small local NGOs including Educate the Children, FORWARD, ZIBIKA and DIPSHIKA as well as Nepal's Agricultural Development Office and Bangladesh's Department of Agricultural Extension. Training, instructional materials, technical backstopping and monitoring were provided through our NARS partners (Figure 5) and interfaced with existing NGO/extension programs.

The primary target crop for HST was rice, but successful testing of the technology for vegetables also allowed application of HST for higher value, income- generating crops. Farmers used HST for a variety of vegetables and observed substantial yield increases averaging 20-40 percent along with improved quality of produce (Figure 6). In addition farmers used less pesticide because of the improved, vigorous growth with HST (Figure 7).

Several entrepreneurial farmers quickly adapted HST for more economic gain. These included selling healthy seedlings of vegetables, rice and tree saplings at premium prices, producing flowers for the highly lucrative and growing Kathmandu city flower market, and utilizing for high value but generally low producing garlic and watermelon markets (Figure 8). The commercial seed sector also benefitted from HST. East West Seed Company, Inc. used HST to increase the quality, size and yields of their vegetable seed stocks (Figure 9). As a result the Company is disseminating the technology to ~3,200 hybrid contract seed growers in NW Bangladesh.

HST adoption was assessed for the CARE Bangladesh, CARE Nepal, RDRS, Educate the Children and Morang Agricultural Development Office programs. Overall adoption of HST for rice was moderate ranging from 10 to 65%, percent, one to two years after introduction. HST adoption for vegetables tended to be higher, ranging from 25-80 percent%. Increased food security and economic benefits were

Figure 6. Bangladeshi farmers with tomato plants produced from HST. (Photos: J. Duxbury)

Figure 7. Vigorous growth of HST eggplants (background) meant this farmer did not have to apply as much pesticide as he would for his normal plants (foreground).

Figure 8. Entrepreneurial farmers use HST for tree saplings, watermelon and flower production. (Photos: R. Hedlund; J. Duxbury; J. Duxbury)

reported by many of the farmers. While HST increased production costs by 3-27 percent (depending on area and vegetable), yield increases and 15-25 percent higher prices from better quality produce, led to net increases in income of $6-11 per decimal (1 decimal=0.01 Acre) compared to conventional practice.

Scaling up efforts involved linking with existing value chain and knowledge support programs. Promotional/awareness raising posters (Figure 10) and hands-on training were provided to Winrock and International Development Enterprises (IDE) agricultural input supplier networks throughout Nepal and Bangladesh. Intercooperation staff and resource persons were trained to bring knowledge on HST into their extensive knowledge support network of 3,600 local service providers and 6,000 commercial nursery growers throughout most of Bangladesh.

Figure 9. Hybrid chili plants at an East West Seed Company contract seed farm. Plants from HST on left; plants from normal seedlings on the right. (Photo: J. Duxbury)

Permanent Raised Beds for Increased Productivity, Crop Diversification and Profit

Three experiments were carried out at experiment stations in Nepal and Bangladesh for 3-6 years to test the feasibility and effectiveness of permanent raised beds (PRB) in addressing the economic, water and soil constraints of conventional rice-wheat cropping systems (Figure 11). A ridge-and-furrow planting configuration maintained for all crops with only periodic reshaping was compared with conventional flat planting in a triple crop rotation of rice-wheat-mungbean. We anticipated that less tillage with the bed system would reduce farmers' labor and diesel input costs while rebuilding soil aggregates and organic matter over time. Water inputs would be reduced substantially by mov-

Figure 10. HST awareness raising poster for Nepali agricultural input supply shop. (Photo: J. Lauren)

Figure 11. Permanent raised bed experiments: rice season at Ranighat, Nepal (left) and wheat season at Dinajpur, Bangladesh (right). (Photos: J. Duxbury, A.S.M.H.M. Talukder)

ing to a furrow irrigation system compared to the conventional flood irrigation, and fertilizer N recovery would be improved on beds. Also timely planting, good crop stands and an improved rooting environment with permanent beds would increase yields and crop diversification opportunities.

Over the duration of these experiments, yields from all crops grown on beds were consistently higher than conventional practice with the exception of wheat at the Nepal site. Fertilizer N recovery in grain was higher on beds than on the flat and more with rice than wheat. And at all three sites furrow irrigation reduced water applications by 21-33 percent for wheat, 14-38 percent for rice and 16-33 percent for mungbean, relative to the conventional practice. As expected reduced tillage operations associated with PRB led to increases in soil carbon stocks of ~0.78 t C/ha/year.

Figure 12. Farmers receiving hands-on training for the power tiller cum bed former. (Photo: C. Meisner)

Farmer experimentation with PRB was initiated in response to farmers' requests to help reduce labor/input costs and to diversify their cropping system for more profitable production. Farmers from three villages in Rajshahi-Natore districts of Bangladesh were recruited and provided hands-on training at the BARI-Rajshahi experiment station on how to prepare the beds using a power tiller with a bed former/seed drill attachment (Figure 12). Farmers then compared crop performance from PRB with conventional flat practice on their own land. A research scientist from the BARI station provided technical backstopping and monitoring support throughout.

Figure 13. Farmers endorsing the use of bed planting for rice and mungbean. (Photos: C. Meisner, J. Duxbury)

Participating farmers were enthusiastic about PRB because the practice improved livelihoods and food security for their families (Figure 13). They reported yield increases in wheat and rice of 15-25 percent along with decreased costs for irrigation (31 to 39 percent) and seed

(20 to 29 percent). Increased efficiency of nitrogen on beds was evident in the field (Figure 14), which translated into 15 percent lower fertilizer costs. Farmers also noted significantly less rat damage, normally a major problem for wheat cultivation in Bangladesh. Initial land preparation costs for beds were 33 to 35 percent higher than for conventional practice, but in subsequent crops, only reshaping the beds saved US$11-28/ha in tillage costs compared to conventional practice. 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. A simple mechanical weeding tool was developed by the lead farmer group to facilitate weeding between the beds (Figure 15). Total costs for farmers using PRB were 12-15 percent lower than for conventional practice. Net incomes from sales of wheat or rice were on average US$17/ha/crop higher using permanent beds.

Tillage and irrigation operations are often limited during the hot and dry conditions of spring and early summer. Nevertheless the minimum tillage and improved water use efficiency of PRB makes cropping during this period feasible. Farmers diversified their crop production by growing mungbean, maize, sesame, hybrid rice and jute on beds during the spring and early summer (Figure 16). Mungbean or maize production on beds during normally fallow periods generated US$49-53/ha net income.

Interest in PRB expanded beyond the initial groups to farmers in a federation of 22 community groups, which were former CARE farmer field schools. The Alipur farmer group took the lead to disseminate PRB to the other groups through farmer rallies and hands-on equipment trainings (Figure 17). Group members who obtained loans for purchasing equipment from a local NGO provided tillage-bed formation services on a for-hire basis. Farmers shared their experiences with the technology and received technical backstopping from a national agricultural scientist and an enthusiastic farmer advocate. Consequently adoption of PRB has grown from 26 farmers on 10 acres in 2003 to over 900 farmers on 486 acres by 2008.

Figure 14. Visual color differences of rice on beds versus conventional flat (background) are consistent with improved fertilizer N recovery.

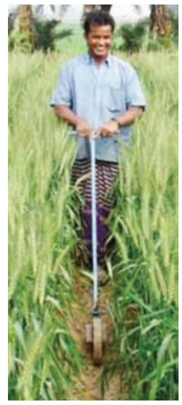

Figure 15. Farmer designed weeding tool for furrow area of beds. (Photo: C. Meisner)

Developing a National Lime Program for Bangladesh

Extensive soil survey data from the Bangladesh Soil Resource Development Institute (SRDI) have been utilized to map the extent of soil acidity in Bangladesh. Approximately 2 million ha of the total cultivated land has strongly acidic soils (pH < 5.5) that would be responsive to lime application (Figure 18). In addition about 5.3 million farm households and much of the

Figure 16. Mungbean (top) and jute (bottom) crop diversification options with raised beds. (Photos: J. Duxbury)

Figure 17. Farmer rally and hands-on equipment training for PRB. (Photos: C. Meisner)

newly developed areas of maize cultivation are on these strongly acid soils.

Liming experiments were initiated in Bangladesh during Phase 1 to assess initial and residual effects from a single lime application and to determine whether interactions with micronutrient availability could be detrimental given the prevalence of micronutrient deficiency problems in the region. Experiments carried out at the Wheat Research Center (WRC) and on local farms in the Dinajpur district established that a single application of lime could sustain rice and wheat productivity increases up to three years. No negative impacts of lime on micronutrient availability were observed at lime rates up to 4 t/ha.

Lime recommendations were developed for Bangladesh during Phase 2. GIS databases were utilized to classify acid soils into significant areas with similar texture and clay mineralogies. Soil samples were collected from 27 of the classes and analyzed to determine lime recommendations using NuMaSS (see the *NuMaSS Project Final Reports* found in this publication), soil-lime incubation and Shoemaker-McLean-Pratt (SMP) buffer approaches. Predicted lime rates were highest from soil-lime incubation and lowest with NuMaSS. In northwestern Bangladesh, predicted lime rates ranged from 1.5 to 4.5 t/ha. Similar lime levels were determined for eastern Bangladesh by the soil-lime incubation, but the SMP buffer and NuMaSS predicted lesser amounts, because aluminum saturation levels in these areas were quite low.

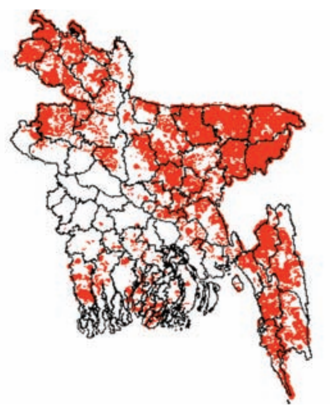

Figure 18. Strongly acid soils (pH<5.5) in Bangladesh. (Source: Bangladesh Soil Resources Development Institute)

Replicated field trials were established at six sites in NW Bangladesh to compare wheat, maize and rice yield responses to a single application of lime across a range of levels predicted by the NuMaSS, soil-lime incubation and SMP approaches (Figure 19). Non-replicated trials were established on farmer fields in Patgram (northwest), Comilla (southeast), Khagrachari and Rangamati (far southeast) in collaboration with Doyel Agro-Industries (a commercial poultry feed manufacturer) and Winrock's BREAD II program (Figure 20). At the NW Bangladesh sites, maximum yield responses to lime were at the 1-2 t/ha rates and were equivalent to that predicted by NuMaSS. At the southeastern sites, maximum yield responses to lime were at the 2-4 t/ha rates and were similar to the soil-lime incubation predictions. Despite potentially higher yields with higher lime rates, farmers preferred the 1-2 t/ha rates as the most economical.

Lime applied at 1-2 t/ha rates to strongly acid soils increased maize yields on average by 2.5 t/ha, wheat by 0.8 t/ha, rice by 0.5 t/ha and legumes such as peanut, chickpea

Figure 19. Lime application for replicated verification trial. (Photo: Md. Bodruzzaman)

Figure 20. Non replicated farm trial to assess maize response to different lime rates: 0 t/ha lime (foreground), 8 t/ha lime (background). (Photo: J. Lauren)

and mungbean by 0.5-1 t/ha. Farmers also report significant benefits to high value spice and vegetable crops. Farm households can realize higher net incomes of $200-$300/ha from maize and legumes, and $150/ha from wheat after applying lime. Lime application costs ($70-140/ha) can be distributed over time as the lime had significant residual effects on 3-5 subsequent crops.

LESSONS LEARNED AND NEXT STEPS

- Development and verification of technology adoption processes for the Healthy Seedling Technology, Permanent Raised Beds and Lime has led to the following lessons learned and opportunities for future research:

- Technology dissemination agents and farmers prefer simple technologies with broad application and clear economic or food security benefits. HST fit this requirement through its application for rice and high value vegetables, flowers, tree saplings and quality seed production. Nevertheless, appropriate biophysical or socioeconomic targeting is also necessary to encourage adoption. For example, HST is most effective and worth the investment where high levels of nematode galls or other root health problems exist. Some NGO officers tended to overlook targeting in their zeal to assist their clients. In one case, access to sufficient land was a key factor, so not surprisingly HST adoption was quite low by landless farmers with only small homestead areas. On the other hand, large-area farmers trying to increase cash flow did not adopt HST for rice due to low market prices, but were willing to utilize the technology for high value vegetables.

- Our NGO and extension partners periodically documented technology impacts, but rarely documented farmer-to-farmer transfer or adoption. Our program took the lead to fill this gap in order to gain a better understanding of farmers' knowledge following technology dissemination, to estimate the extent of secondary adopters and to identify what factors caused farmers to adopt or not adopt HST.

- The transfer agents that we worked with on HST dissemination were committed to their programs and had good national staff, who worked very hard. CARE, RDRS and ETC's commitment to employing women and working with women farmers was particularly notable. Training was done correctly by most of the transfer partners, although lack of coordination and hands-on demonstrations resulted in poor delivery of the HST message by one NGO. Technical backstopping by our NARS partners helped to identify and correct this problem.

- Focusing on a single tillage/cultivation approach and having a strong linkage between the NARS and a local farmer advocate facilitated adoption and expansion of the PRB technology. In addition, an active community-based farmer organization was very helpful in advancing this technology. Any future expansion programs will need funding to support technical backstopping and farmer-to-farmer training. Also linking farmers with organizations who provide meso-credit loans without collateral for purchasing power tillers-bed formers will be a key factor for expansion.

- We documented the economic, labor and natural resource benefits of permanent beds for the rice-wheat cropping system in Bangladesh. Additional research is needed to evaluate the impacts of this technology at ecosystem/landscape scales; to identify and research modifications that will facilitate further adoption in other environments; and to address constraints that arise in response to system modifications.

- Encouraging adoption by providing incentives such as seeds and fertilizer is a common practice by various donor groups, international centers, NARS and extension agencies. We found that incentives led to a culture of expectancy and dependence. Some support during initial technology development or evaluation may be necessary, but it should be withdrawn as soon as possible. Colleagues in other groups continued to give incentives throughout a project, which often put us in an awkward situation.

- Bringing NARS scientists, technology transfer partners and community based farmer groups together raised awareness and promoted understanding between the stakeholders concerning their needs and limitations. Our program encouraged routine interactions between these groups, and built sustainable linkages and relationships that will last beyond the project. More demand-driven research is the likely outcome of having research scientists working more closely with farmers and technology transfer agents.

- Sustainability is difficult, especially with NGOs working from project to project and government extension having low funding and poor capacity. Knowledge support systems such as Intercooperation's local service providers linked to NARS and extension knowledge sources, CARE's empowered community based farmer groups, or the Winrock and IDE agricultural input supplier networks are effective and sustainable avenues for imparting and providing longer term support of agricultural and natural resource knowledge transfer. The local service provider and input supplier network approaches also form the basis for scaling-up to national scales.

- White papers describing the benefits and impacts of HST and lime were provided to the Bangladesh Agricultural Research Council as a first step to getting knowledge about these technologies to policy makers and to move towards scaling up through the government extension system. While financial resources are currently available through a large World Bank loan, an unwieldy bureaucracy has delayed national dissemination of these successful technologies.

The Healthy Seedlings Technology has improved the food security and livelihood situation for Anwara Begum and her family. (Photo: J. Duxbury)

PARTICIPATING AND COLLABORATING SCIENTISTS & INSTITUTIONS/ORGANIZATIONS

National Agricultural Research Systems (NARS)

Bangladesh

Bangladesh Agricultural Research Institute (BARI)
Md. Badaruddin
M.E. Baksh
Md. Bodruzzaman
A.B.S. Hossain
A.E. Hossain
M.I. Hossain
P.K. Malaker
Md. A. Mannan
A.K. Maqbul Hossain
S. Banu Parvin
M.A. Rahman
M.A. Razzaque
M. Saifuzzaman
M.A. Samad
M.A. Shaheed
M.A. Sufian
A.M.H.S. Talukdhar

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

Bangladesh Rural Advancement Committee--NGO (BRAC)
Md. Abubakar
S. Ch. Nath
Md. A. Saleque

Bangladesh Rice Research Institute (BRRI)
H.U. Ahmed
Z.U. Ahmed
N.I. Bhuiyan
N.H. Chaudhury
T. Das
N. E-Elahi
R. Karim
S.M.R. Karim
M.A. Khan
M.A. Mazid (IFAD)
M. Miah
B.A.A. Mustafi
N. Nahar
M.D. Nurul Islam
G.M. Panaullah
D.N.S. Paul

Cooperative for American Relief Everywhere--NGO (CARE)
A. Rahman
N.D. Tex
G.U. Talukdhar (IDE)

InterCooperation, International NGO (Swiss) (IC)
A. Cuvelier
N. Islam
A. Quddus

International Development Enterprise, International--NGO (IDE)
Md. B. Islam
L. Payne

Rangpur Dinajpur Rural Service—NGO (RDRS)
M.G. Neogi
S. Samsuzzaman

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

India

G.B. Pantnagar University
Yatinder Singh

*Indian Council of Agricultural Research (*ICAR)
R.K. Gupta

Punjab Agricultural University, Ludhiana, (PAU)
C.L. Arora
S. Beedi
M.R. Chaudhary
P.R. Gajri
N. Jead
P.P.S. Pannu
Bijay Singh
Yadvinder Singh

Nepal

Cooperative for American Relief Everywhere International—NGO (CARE)
R. Karnal
B.K. Pokharel
M. Pradan
B. Thapa

District Agricultural Development Office (DADO)
R. Upreti

Educate the Children—Nepal NGO (ETC)

C. London
M.M.S. Rana

Institute for Agriculture and Animal Science (IAAS)
L.P. Amgain
K.B. Basnet
K.R. Dahal
R.R. Pokharel
S.C. Sah
S.M. Shrestha
D.N. Yadav

Nepal Agriculture Research Council (NARC)
C. Adhikari
D. Bhandari
S. Bhattarai
H. Bimb
S.K. Gami
D.B. Gharti
M. Ghimire
G.S. Giri
D. Joshi
C.B. Karki
S.M. Maskey
M. Mishra
S.P. Pandey
D.S. Pathick
T. Pokharel
N.K. Rajbhandari
J.D. Ranjit
G. Sah
K. Sah
R.P. Sapkota
S. Sharma
R.K. Shrestha
R. Shrestha
J. Tripathi
H.K. Upreti

Winrock International
L.A. Colavito

Winrock-SIMI
B. Bhatta
B.K. Gurung

Pakistan

Pakitan Agricultural Research Council (PARC)
Md. Saleem Akhtar
Md. Salim

Thailand

Mahasarakham University
P. Khangkhun
M. Wongsawas

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

United Kingdom

J. Bridge (CABI Bioscience)
J. Gaunt (Rothamsted Exp. Station)
M. Halderness (CABI Bioscience)
D. Harris (Univ. of Wales; DFID-Plant Sciences Research
K.D. Joshi (Univ. of Wales; DFID-Plant Sciences Research

United States

Cornell University
G. Abawi
P. Baveye
R. Bellinder
G. Bergstrom
S. DeGloria
J. Duxbury
S. Feldman
P.K. Kataki (Cornell On-Site Coordinator—India)
S. Kyle
M. Latham
J. Lauren
D. Lee
C.A. Meisner (CIMMYT & Cornell On-Site Coordinator—Bangladesh)
R. Obendorf
S. Riha
J. Ritchie (Michigan State University
J. Thies
N. Uphoff
R. Welch (US Plant, Soil & Nutrition Lab)
T. Widmer

International Agricultural Research Centers (IARC)

International Maize and Wheat Improvement Center (CIMMYT)

E. Duveiller (Nepal)
L. Harrington (Mexico)
P.R. Hobbs (Nepal)

D. Hodson (Mexico)
S. Justice (Nepal)
M. Ortiz-Ferrera (Nepal)
K. Sayre (Mexico)
J. White (Mexico)

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)

C. Johansen

International Rice Research Institute (IRRI)

I.P. Abrol (Rice-Wheat/Bangladesh)
K. Bronson
S.P. Kam
J.K. Ladha

Private Sector

Doyel Agro Complex, Ltd.
Md. M. Haque
E. Hossain

East West Seeds, Inc.
M.G. Hossain
W. Zaman

SALMAR
A.S. Titu

TRAINING AND DEGREE PROGRAMS

Degree Programs

Year	Name	Degree	Gender	Institution	Home Country
1998	Krishna Rao	MSc	M	Cornell University	India
2000	Medha Devare	PhD	F	Cornell University	India
2001	Deepak Bhandari	MSc	M	Inst. Agric. Animal Sci	Nepal
2001	Deepak Sharma Poudyal	MSc	M	Inst. Agric. Animal Sci.	Nepal
2001	Bishnu Adhikari	MSc	M	Inst. Agric. Animal Sci.	Nepal
2002	Kaafee Billah	PhD	M	Cornell University	Bangladesh
2002	Dil Raj Yadav	MSc	M	Inst. Agric. Animal Sci.	Nepal
2002	Narayan Khanal	MSc	M	Inst. Agric. Animal Sci.	Nepal
2002	Dinesh Adhikari	MSc	M	Inst. Agric. Animal Sci.	Nepal
2002	Krishna P. Devkota	MSc	M	Inst. Agric. Animal Sci.	Nepal
2003	Jonathan Padgham	PhD	M	Cornell University	USA
2003	Andrew McDonald	PhD	M	Cornell University	USA
2003	Gopal Bhatta	MSc	M	Inst. Agric. Animal Sci.	Nepal
2003	Rishi Ram Birlakoti	MSc	M	Inst. Agric. Animal Sci.	Nepal
2003	Janma Jaya Gairhe	MSc	M	Inst. Agric. Animal Sci.	Nepal
2004	Sarah Johnson	PhD	F	Cornell University	USA
2004	Ann Marie Mayer	PhD	F	Cornell University	England
2005	Steven Culman	MSc	M	Cornell University	USA
2005	Md. Ektear Uddin	MSc	M	Bangladesh Agric. Univ	Bangladesh
2006	Ramesh Pokharel	PhD	M	Cornell University	Nepal
2008	Md. Bodruzzaman	PhD	M	Bangladesh Agric. Univ	Bangladesh

Non-Degree Programs

Name	Home Country	Gender	Dates
Yatinder Singh	India	M	Jan-Feb 1997
Salina Parvin	Bangladesh	F	Sept 1997
Raj P. Sharma	Bangladesh	M	Sept 1997
Md. Saifuzzaman	Bangladesh	M	Sept 1997
C.L. Arora	India	M	Nov 1997
Md. Saleem Akhtar	Pakistan	M	Feb-July 1998
Jai Pal Singh	India	M	June-Oct 1998
P.R. Gajri	India	M	July 1998
Salina Parvin	Bangladesh	F	Sept 1998
Md. Bodruzzaman	Bangladesh	M	Sept 1998
Yadvinder Singh	India	M	Sept l998-Jan 1999
Bijay Singh	India	M	Sept-Nov 1998
Salina Parvin	Bangladesh	F	April 1999
Hafiz Ahmed	Bangladesh	M	April 1999
Ramesh Pokharel	Nepal	M	April 1999
Ramesh Upreti	Nepal	M	April 1999
S. Rawat	Nepal	M	July-Aug 1999
S. Chaudhary	Nepal	M	July-Aug 1999
Golam Panaullah	Bangladesh	M	Jan 2000
Nur E-Elahi	Bangladesh	M	Jan 2000
Md. Saifuzzaman	Bangladesh	M	Jan 2000
Md. Ataur Rahman	Bangladesh	M	Jan 2000
Md. Saifuzzaman	Bangladesh	M	April 2000
Debi Paul	Bangladesh	M	Nov 2000
Zia Ahmed	Bangladesh	M	Nov 2000
Anwar Shaheed	Bangladesh	M	Jan 2001
Md. Al-Amin	Bangladesh	M	Jan 2001
M.A. Nahar	Bangladesh	F	Jan 2001
M.A. Begum	Bangladesh	F	Jan 2001
Ramesh Pokharel	Nepal	M	Jan 2001
Sundar Shrestha	Nepal	M	Jan 2001
Sarala Sharma	Nepal	F	Jan 2001
Dil Gharti	Nepal	M	Jan 2001
Md. Saifuzzaman	Bangladesh	M	Oct 2001
Nurul Bhuiyan	Bangladesh	M	Nov 2001
Md. Bodruzzaman	Bangladesh	M	Aug 2002
Salina Parvin	Bangladesh	F	Aug 2002
Anwar Shaheed	Bangladesh	M	Aug 2002
Md. Saifuzzaman	Bangladesh	M	Aug 2002
Md. Ataur Rahman	Bangladesh	M	Aug 2002
A.S.M. Talukder	Bangladesh	M	Aug 2002
Md. Abdus Samad	Bangladesh	M	Aug 2002
Surya Maskey	Nepal	F	Aug 2002-Jan 2003
Md. Bodruzzaman	Bangladesh	M	July-Aug 2003

Workshops

Title	Dates	Location	Gender
National Scientists Traveling Workshop	Mar 6-16,1997	Nepal, Bangladesh NARC	14M, 2F
Harmonization of Databases for GIS Analysis of Cropping Systems in Asia	Aug 18-19,1997	ICRISAT-Asia Centre Pantancheru, India	11M,1F
Use of GIS in Analysis of Cropping Systems	Aug 20-29, 1997	ICRISAT-Asia Centre Pantancheru, India	18M,2F
Legumes in Rice-Wheat Cropping Systems of the Indo-Gangetic Plain:Constraints & Opportunities	Oct 15-17, 1997	ICRISAT-Asia Centre Pantancheru, India	16M,2F
DSSAT Models for Rice-Wheat Cropping Systems	Nov 20-21, 1997	Joydebpur, Bangladesh	19M, 2F
National Scientists Traveling Workshop on Tillage and Crop Establishment	Mar 26-Apr 6, 1998	E. Pakistan, W.India NARC	25M
Regional Tech. Coordinating Committee, Rice-Wheat Consortium	Sept 12-13, 1998	Kathmandu Nepal	13M,1F
GIS Applications in Rice-Wheat System Research and Development	Jan 2002	Gazipur, Bangladesh	7M,3F
Healthy Seedlings hands-on Training for CARE-Bangladesh, BRAC and Bangladesh DAE officers	Oct 30, 2002	Dinajpur Bangladesh	29M
Healthy Seedlings hands-on training for CARE-Nepal farmers and officers	April 25, 2003	Mahottari & Sarlahi Nepal	22M,30
A Where-Atlas Characterization Tool Workshop for the Bangladesh Country Almanac	June 2-6, 2003	USA	9M,2F
Multi-Stakeholder Evaluation of Permanent Bed Technology for The Rice-Wheat System	Jan 22, 2004	Dhaka Bangladesh	12M,1F
Regional Healthy Seedlings Dissemination Evaluation Workshop	March 24-25, 2004	Rangpur, Bangladesh	23M,1F
Health Seedlings hands-on training for CARE-Bangladesh BRAC, RDRS, East West Seeds and Bangladesh DAE officers	June 24, 2004	Dinajpur Bangladesh	35M,1F

Title	Dates	Location	Gender
Healthy Seedlings hands-on training for Winrock-SIMI	Oct 8, 2004	Bhairahawa, Nepal	20M,6F
Healthy Seedlings hands-on training for RDRS farmer groups	Oct 28,30, 2004	Bangladesh	38M,4F
Healthy Seedlings hands-on Training for Educate the Children	April 6,8, 2005	Kathmandu Valley & Lalitpur, Nepal	3M,27F
Permanent Beds – Field Day	March 20, 2005	Durgapur, Bangladesh	200M
Lime Field Days	Feb 20; Apr 21, 2005	Patgram, Bangladesh	286M
Healthy Seedlings hands-on trainings for Winrock, SIMI, CARE Nepal and ETC	Aug, Sept 2005 March 2006	Nepalgunj, Bardibas & Godavari, Nepal	150M, 279F
Healthy Seedlings hands-on trainings for RDRS, commercial seedling dealers, East West contract seed growers	Aug, Sept 2005	Kurigram,Nilphamari Khansama, Thakurgaon,Dinajpur,	51M,17F
Lime farmer field day	Feb 24, 2006	Birgonj, Bangladesh	80M
Perm. Beds farmer rally	March 8, 2006	Durgapur, Bangladesh	204M
Perm. Beds farmer to farmer training for mungbean/rice	April 12,13, 2006 April 12,13, 2006	Durgapur Bangladesh	96M,4F
Perm. Beds farmer to farmer training for wheat	Nov 5, 2006 Nov 5, 2006	Durgapur Bangladesh	295M,5F 295M, 5F
Healthy Seedlings hands-on trainings for DIPSHIKA, ZIBIKA and RDRS	April-May 2006	Lalmonirhat & Dinajpur, Bangladesh	82M,23F
Healthy Seedlings trainings for Winrock SIMI agrovets, NARS and ADO officers	Jan, Apr, May 2007	Palpa,Bhairahawa, Parwanipur, Hardinath & Tarahara, Nepal	107M
Healthy Seedlings trainings for IDE agro-vets, IC local service providers and nursery owners	May-June 2007	NW and WC, Bangladesh	255M,120F
Perm. Beds farmer rally	Feb 22, 2007	Durgapur, Bangladesh	217M, 10F
Perm. Beds farmer to farmer training for rice	June 12, 14 2007	Durgapur Bangladesh	126M,6F

PUBLICATIONS, PRESENTATIONS AND REPORTS

Journal Series and Books

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Banu, S.P., M.A. Shaheed, A.A. Siddique, M.A. Nahar, H.U. Ahmed, M.H. Devare, J.M. Duxbury, J.G. Lauren, G.S. Abawi and C.A. Meisner. 2005. Soil biological health: A major constraint in the rice-wheat cropping system. Int. Rice Res. Notes 30(1):5-11.

Bodruzzaman, M., J.G. Lauren, J.M. Duxbury, M.A. Sadat, R.M. Welch, N. E-Elahi and C.A. Meisner. 2005. Increasing wheatand rice productivity in the sub-tropics using micronutrient enriched seed. *In:* P. Andersen et al. (eds). Micronutrients in South and South East Asia. Proc. International Workshop, Kathmandu, Nepal, 8-11 Sept. 2004. Int. Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal, pp. 187-198.

Culman, S., J.M. Duxbury, J.G. Lauren and J.E. Thies. 2006. Microbial community response to soil solarization in Nepal's rice-wheat cropping system. Soil Biol. Biochem. 38:3359-3371.

Duxbury, J.M., I.P. Abrol, R. Gupta and K. Bronson. 2000. Analysis of long-term soil fertility experiments with rice-wheat rotations in S. Asia. *In:* I.P. Abrol et al. (eds). Long-Term Soil Fertility Experiments in Rice-Wheat cropping Systems. Rice-Wheat Consortium Paper Series No. 6. Rice-Wheat Consortium for the Indo-Gangetic Plains. CIMMYT, New Delhi, India.

Duxbury, J.M. 2001. Long-term yield trends in the rice-wheat cropping system: Results from experiments and northwest India. *In:* P.K. Kataki (ed). The Rice-Wheat Cropping System of South Asia: Trends, Constraints, Productivity & Policy Issues. J. Crop Production. 3(2):27-52

Duxbury, J.M., J.G. Lauren, M.H. Devare, A.S.M.H.M. Talukdar, M.A. Sufian, A.Shaheed, M.I. Hossain, K.R. Dahal, J. Tripathi, G.S. Giri and C.A. Meisner. 2004.Opportunities and constraints for reduced tillage practices in the rice-wheat cropping system. pp. 121-131. *In:* R. Lal, P.R. Hobbs, N. Uphoff, D.O. Hansen (eds). Sustainable Agriculture and the International Rice-Wheat System. Marcel Dekker, Inc. New York.

Hobbs, P.R., Y.Singh, G.S.Giri, J.G. Lauren and J.M. Duxbury. 2002. pp. 201-215. *In:* S.Pandey et al. (eds). Direct Seeding and Reduced Tillage Options in the Rice-Wheat Systems of the Indo-Gangetic Plains of South Asia. Proc. Int. Rice Res. Instit.Workshop 'Direct Seeding in Asian Rice Systems.' Bangkok, Thailand. 25-28 January 2000.

Johansen, C., J. Duxbury, S.M. Virmani, C.L. Gowda, S. Pande and P.K. Joshi. 2000. Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain – constraints and opportunities. ICRISAT and Cornell University. Patancheru 502324, Andhra Pradesh, India. 223p.

Johansen, C., A.M. Musa, J.V.D.K. Kumar Rao, D. Harris, M. Y. Ali, A.K.M. Shahidullah and J.G. Lauren. 2007. Correcting molybdenum deficiency of chickpea in the High Barind Tract of Bangladesh. J. Plant Nutr. Soil Sci. 170:1-10.

Johnson, S.E., J.G. Lauren, R.M. Welch and J.M. Duxbury. 2005. A comparison of the effects of micronutrient seed priming and soil fertilization on the mineral nutrition of chickpea (Cicer arietinum), lentil (Lens culinaris), rice (Oryza sativa), and wheat (Triticum aestivum) in Nepal. Experimental Agriculture. 41(4):427-448.

Kataki, P.K., P.Hobbs and B. Adhikari. 2000. The rice-wheat cropping system of South Asia: Trends, constraints and productivity - A prologue. *In:* P.K. Kataki (ed). The Rice-Wheat Cropping System of South Asia: Trends, Constraints, Productivity & Policy Issues. J. Crop Production. 3(2):1-26.

Kataki, P.K., S. Bedi, C.L. Arora, J.G. Lauren and J.M. Duxbury. 2001. Performance of micronutrient enriched wheat seeds on three soil types. J. New Seeds. 3(4):13-21.

Kataki, P.K., H.K. Upreti and M.R. Bhatta. 2001. Soil boron deficiency induced wheat sterility in Nepal: Response to boron and nitrogen application. J. New Seeds. 3(4):23-39.

Kataki, P.K., S.P. Srivastava, M. Saifuzzaman and H.K. Upreti. 2002. Sterility in wheat and response of field crops to applied boron in the Indo-Gangetic Plains. *In:* P.K. Kataki (ed). The Rice-Wheat Cropping System of South Asia: Efficient Production Management. 4:133-165.

Ladha, J.K., J.E. Hill, J.M. Duxbury, R.K. Gupta and R.J. Buresh. 2003. Improving the productivity and sustainability of rice-wheat systems: Issues and Impacts. SA Special Publication No. 65, Amer. Soc. Agron., Madison, WI.

Lauren, J.G., J.M. Duxbury, V. Beri, M.A.Razzaque II, M.A. Sattar, S.P. Pandey, S. Bhattarai, R.A. Mann and J.K. Ladha. 1998. Direct and residual effects from forage and green manure legumes in rice-based cropping systems. pp. 55-81. *In:* J.V.D.K. Kumar Rao, C. Johansen and T.J. Rego (eds). Residual Effects of Legumes in Rice and Wheat Systems of the Indo-Gangetic Plain. Oxford & IBH Publishing Co., Pvt. Ltd. New Delhi, India.

Lauren, J.G., R.Shrestha, M.A. Sattar and R.L. Yadav. 2001. Legumes and diversification of the rice-wheat cropping system. *In:* P.K. Kataki (ed). The Rice-Wheat Cropping System of South Asia: Efficient Production Management J. Crop Production. 3(2):67-102.

Lauren, J.G., G. Shah, M.I. Hossain, A.S.M.H.M. Talukder, J.M. Duxbury, C.A. Meisner and C. Adhikari. 2008. 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 No. 127, Canberra, Australia, pp. 124-132.

McDonald, A.J., S.J. Riha, J.M. Duxbury and J.G. Lauren. 2006. Wheat responses to novel rice cultural practices and soil moisture conditions in the rice-wheat rotation of Nepal. Field Crops Research 98:116-126.

McDonald, A.J., S.J. Riha, J.M. Duxbury, T.S. Steenhuis and J.G. Lauren. 2006. Water balance and rice growth responses to direct seeding, deep tillage, and landscape placement: Findings from a valley terrace in Nepal. Field Crops Res. 95:367-382.

McDonald, A.J., S.J. Riha, J.M. Duxbury, T.S. Steenhuis and J.G. Lauren. 2006. Soil physical responses to novel rice cultural practices in the rice-wheat system: Comparative evidence from a swelling soil in Nepal. Soil & Tillage Res. 86:163-175.

Meisner, C.A., R. Welch, J.M. Duxbury and J.G. Lauren. 2005. Making a greener revolution: A nutrient delivery system to address malnutrition through crop science. Plant-Production Sci. 8:326-329.

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Padgham, J.L., J. M. Duxbury, M. A. Mazid, G. S. Abawi and M. Hossain. 2004. Yield loss caused by Meloidogyne graminicola on lowland rainfed rice in Bangladesh. Journal-of-Nematology. 36:42-48.

Rahman, M.A., C.A. Meisner, J.M. Duxbury, J. Lauren and A.B.S. Hossain. 2001. Yield response and change in nutrient availability by application of lime, fertilizer and micronutrients in acidic soil within a rice-wheat cropping system. Bangladesh J. Agric. Res. 26(3):357-365.

Rahman, M.A., J. Chikushi, J.M. Duxbury, C.A. Meisner, J.G. Lauren and E. Yasunaga. 2005. Chemical control of soil environment by lime and nutrients to improve productivityof acidic alluvial soils under rice-wheat cropping system in Bangladesh. Environ. Control Biol. 43(4):259-266.

Rahman, M.A., J. Chikushi, M. Saifuzzaman and J.G. Lauren. 2005. Rice straw mulching and nitrogen response of no-till wheat following rice in Bangladesh. Field Crops Res. 91: 71-81.

Presentations and Reports

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Adhikari, C., J.G. Lauren and J.M. Duxbury. 2007. Improved root health with solarization increases rice and vegetable production. 8th National Outreach Workshop,19-20 June 2007, NARC On-Farm Research Division, Kathmandu, Nepal.

Baksh, M.E., M.A. Siddique, C. Meisner, J.M. Duxbury and J.G. Lauren. 2004.Growing healthy rice seedlings through soil solarization: A low cost technology for increasing rice productivity and profitability. *In* T. Fischer et al. (eds). New Directions for a Diverse Planet: Proceedings of the 4th International Crop Science Congress, Brisbane, Australia, 26September–1October2004. http://www.cropscience.org.au/icsc2004/poster/2/4/2/1402_bakshe.htm

Banu, S.P., M.A. Razzaque, J.G. Lauren, J.M. Duxbury and C.A. Meisner. 2002. Soil solarization – A cropping systems perspective research to increase productivity. World Congress of Soil Science, Bangkok, Thailand, 14-21 August 2002.

Banu, S.P., J.M. Duxbury, J.G. Lauren and C.A. Meisner. 2004. Seedbed solarization: A practical tool to increase rice productivity. Mekong Rice Conference, Ho Chi Minh City, Vietnam. 15-17 October 2004.

Banu, S.P., J.M. Duxbury, J.G. Lauren, C. Meisner and R Islam. 2004. Wheat seed quality: A study on farmer seed. *In:* T. Fischer et al. (eds). New Directions for a Diverse Planet: Proceedings of the 4th International Crop Science Congress, Brisbane, Australia, 26 September-1 October 2004.
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Bodruzzaman, M., C.A. Meisner, J.M. Duxbury, R.M.Welch and J.G. Lauren. 1998. Effects of micronutrient seed enrichment on rice-wheat production. In Agronomy abstracts. Am. Soc. Agron, Madison, WI. p. 47.

Bodruzzaman, M., J.M. Duxbury, J.G. Lauren, C. Meisner, M.H.H. Khan and M.A. Sadat. 2004. Response of wheat to enriched seed and boron. *In:* T. Fischer et al. (eds). New Directions for a Diverse Planet: Proceedings for the 4th International Crop Science Congress, Brisbane, Australia, 26 September – 1 October 2004.
http://www.cropscience.org.au/icsc2004/poster/2/5/5/1034badruzzamanm.htm

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Duxbury, J.M., J.G. Lauren, P.K. Kataki, C.A. Meisner and P.R. Hobbs. 1998. Soil management research in South Asia's rice-wheat systems. In Agronomy abstracts. Am. Soc. Agron, Madison, WI. p. 46.

Duxbury, J.M. 2000. Addressing nutrient deficiencies and efficiencies in the rice-wheat cropping system. FAO/IAEA Consultants' Meeting on Integrated Soil, Water and Nutrient Management for Sustainable Rice-Wheat Cropping Systems in Asia, 23-25 August 2000, Rome, Italy.

Duxbury, J.M. 2004. Boron and zinc in agricultural systems: Implications for human nutrition. USDA Grand Forks Human Nutrition Laboratory, Grand Forks, ND.
Duxbury, J.M. 2004. Micronutrient enrichment of rice, wheat and grain legumes by agronomic management. Am. Soc. Agronomy Annual Meetings, Seattle, WA, Oct. 31-Nov. 4, 2004.

Duxbury, J.M. and J.G. Lauren. 2004. Increasing rice productivity in South Asia – Cornell's Soil Management CRSP experience. Int. Rice Res. Institute, Philippines

Duxbury, J.M., M. Bodruzzaman, S. Johnson, A.B.M. Mayer, J.G. Lauren, C.A. Meisnerand R. M. Welch. 2005. Impacts of increased mineral micronutrient content of rice and wheat seed/grain on crop productivity and human nutrition in Bangladesh. pp. 30-31. *In:* C.J. Li et al. (eds). Plant Nutrition for Food Security, Human Health & Environmental Protection, Proc. 15th Int. Plant Nutrition Colloquium. 14-19 September 2005, Beijing, China. Tsinghua Univ. Press.

Duxbury, J.M., M. Bodruzzaman, S.E. Johnson, J.G. Lauren, C.A. Meisner and R.M Welch. 2006. Opportunities and Constraints for Addressing Human Mineral Micronutrient Malnutrition through Soil Management. 18th World Congress of Soil Science, 9-15 July 2006, Philadelphia, PA.

Hossain, M.I., C. Meisner, J.M. Duxbury, J.G. Lauren, M.M. Rahman, M.M. Meer and M.H. Rashid. 2004. Use of raised beds for increasing wheat production in rice-wheat cropping systems. Proceedings of the 4th International Crop Science Congress. Brisbane, Australia, 26 Sept. - 1 Oct 2004.
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Hossain, M.I., C.A. Meisner, M.A. Sufian, J.M. Duxbury, J.G. Lauren and M.M. Rahman. 2005. Use of nutrients on raised beds for increasing rice production in rice-wheat cropping systems. *In* C.J. Li et al. (eds). Plant Nutrition for Food Security, Human Health & Environmental Protection. Proc. 15th Int. Plant Nutrition Colloquium. 14-19 September 2005, Beijing, China, Tsinghua Univ. Press. pp. 888-889.

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Johnson, S.E. and J.M. Duxbury. 2002. Changes in availability of Zn in several soils with redox variation resulting from flooding. American Society of Agronomy Annual Meetings, Indianapolis, IN, 10-14 November 2002.

Johnson, S.E., J.M. Duxbury and J.G. Lauren. 2002. Effect of micronutrient nutrition on disease incidence in grain legumes. American Society of Agronomy Annual Meetings, Indianapolis, IN, 10-14 November 2002.

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Johnson, S.E., J.M. Duxbury, J.G. Lauren and K.R. Dahal. 2003. Effect of micronutrient seed priming on mineral nutrition of various crops in the rice-wheat system. ASA Annual Meetings, Denver, CO, 2-6 November 2003.

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Johnson, S.E., J.G. Lauren, J.M. Duxbury, R.M. Welch, and K.R. Dahal. 2004. Effect of micronutrient solution priming on mineral nutrition and seed enrichment of various crops in the rice-wheat system. International Workshop on Micronutrients in South and South East Asia, Kathmandu, Nepal. 8-11 September 2004.

Lauren, J.G., J.M. Duxbury, M.I. Hossain, G. Sah, A.S.M.H.M. Talukder and C.A.Meisner. 2006. Permanent raised bed cultivation improves nitrogen and water use in rice-wheat cropping systems of South Asia. 18th World Congress of Soil Science, 9-15 July 2006, Philadelphia, PA.

Lauren, J.G. and J.M. Duxbury. 2008. Disseminating soil management knowledge through NGOs: Lessons learned. Am. Soc. Agronomy Annual Meetings, Houston, TX, 5-9 Oct. 2008.

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Chapter Five

Carbon Sequestration

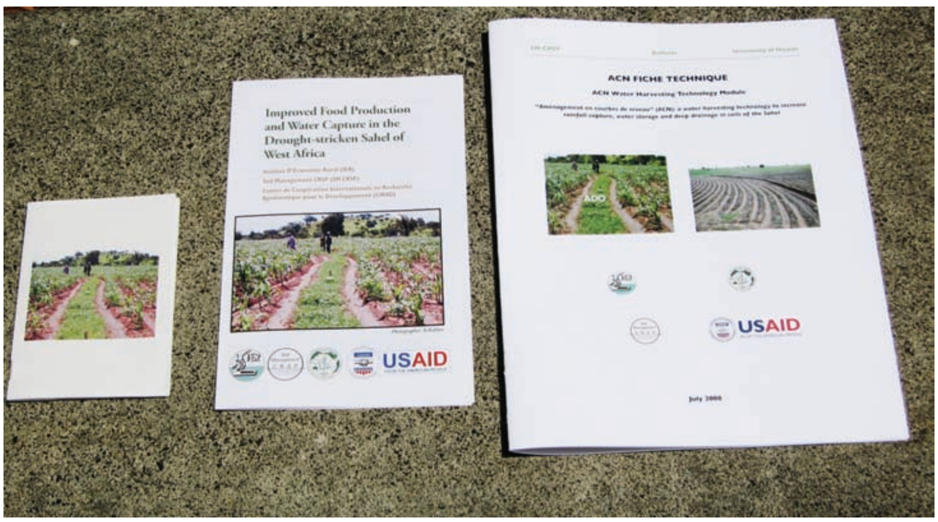
MEASURING AND ASSESSING SOIL CARBON SEQUESTRATION BY AGRICULTURAL SYSTEMS IN DEVELOPING COUNTRIES - WEST AFRICA

RUSSELL YOST, DEPARTMENT OF TROPICAL PLANT AND SOIL SCIENCES
UNIVERSITY OF HAWAII AT MANOA, HONOLULU, HI, USA

UNIVERSITY OF HAWAII

Constructing the permanent ridges of the ACN with a mold board plow.

Table of Contents



OVERVIEW & EXECUTIVE SUMMARY

Climate change is now recognized as a serious threat to our generation and a potential disaster to for future generations. Climate change has already caused severe droughts in West Africa, with a dramatic reduction in amount and regularity of annual rainfall. Solutions to such problems are complicated and thus it is important to begin solving them now. Increased sequestration of C in soil may be one of many components of a sustainable solution. Sequestration of C can help mitigate climate change in two ways. Firstly, the sequestration begins by converting a small portion of the atmospheric C, captured by plants and stored in roots and biomass, into soil organic carbon. Secondly, it mitigates adverse effects of climate change, specifically, by, reducing the effects of droughty conditions by increasing the capacity of the soils to absorb and retain water for food crops. A soil and water conservation technology, "Amenagement en courbes de niveau" or ACN, was developed by the project to capture a portion of the intense tropical rainfall and was tested to determine if it's use also led to increased capture and sequestration of carbon in soils.

This testing of ACN took place in Mali, the country of origin of the technology, and in Senegal and The Gambia. For Senegal and The Gambia we modified ACN for use on "flat" planting rather than on ridges as done in Mali where planting takes place on annually drawn furrows.

Objectives for Phase 2 were:

1. Develop Practical Methods to Measure Gains and Losses of Soil Organic C Over Time in Spatially Variable Soils in West Africa.
2. Assess the Potential for Soil C Sequestration for Selected Sites in West Africa.

PHASE 2 PROJECT ACCOMPLISHMENTS

Objectives 1 and 2 were achieved through a sequence of seven activities:

- Soil organic C laboratory measurement techniques and methods were tested and adapted for West African conditions.
- Soil organic C assessments, and sampling requirements in space and time were developed and tested on a field, multiple field, and watershed or larger basis in West Africa.
- Spatial data were purchased and ground-truthed for a set of six fields in Mali (the villages of Fansirakouro (2 fields), Siguidolo, Oumarbougou, Sougoumba, and Sikasso) that had been placed under the ACN technology and under which the challenge was to assess soil C change.
- The ACN technology was evaluated as to how it affected crop yields, soil water content and soil C sequestration.
- The impacts of ACN technology on groundwater and tree C were assessed.
- Brochures, training, and publications of ACN were prepared to increase its diffusion throughout the West African community.
- Results of the surveys carried out beginning in 2000 and continuing every other two years (e.g., 2002, 2004, and 2006) were returned and discussed with the farmers at each site listed above.

HIGHLIGHTS OF ACCOMPLISHMENTS

Soil Organic C Laboratory Measurement Techniques and Methods Tested and Adapted for West African Conditions

Measuring soil organic C for the purposes of C trading required a level of precision and accuracy beyond that available with conventional agronomic and soil science laboratory practice. The most accurate method, that of measurement using combustion techniques, was not commonly available for scientists in West Africa.

Several other measurement techniques were tested. Results continue to improve the Loss on Ignition (LOI) approach that holds promise to enable laboratories with a relatively low cost muffle furnace and an analytical balance to determine soil organic C. A dissertation study by an Institut d'Economie Rurale, (IER) scientist, Hamidou Konare, conducted at the University of Hawaii tested the LOI method. The study determined that the LOI method was applicable to Malian soils provided calibrations were carried out and the soils analyzed were included in the calibration. On the other hand, LOI measurements on soils not included in the calibration may be in error. For example, soils from The Gambia were tested using the calibration from soils collected in Mali. The results indicated that soil organic C could not be accurately predicted in soils from The Gambia using the Mali calibration. Studies are continuing to ascertain why the calibration is site dependent. A second method of measurement is the Visible Near Infrared Spectroscopy (VNIR). Recent results show this new measurement method has 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*. One limitation is the technique is highly sensitive to the measurement of molecular bonds and linkages, but is not specific to elements or compounds, and thus needs careful calibration to ensure that accurate measurements are obtained. This study was a dissertation study by Hamidou Konaré, "Adapting Loss-on-ignition and Visible near Infrared Methods of Measuring Soil Organic Carbon to Sahelian Soils of West Africa."

Soil Organic C Assessments, Sampling Requirements in Space and Time Developed and Tested on a Field, Multiple Fields and Watershed or Larger Basis in West Africa

In his dissertation research, Antonio Querido, a scientist from Cabo Verde, adapted and tested the recently developed Bayesian Maximum Entropy (BME) method that breaks new ground in combining quantitative data and qualitative data together to achieve improved predictions and assessments of soil organic carbon and factors that affect it. 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. The title of the dissertation was "Quantifying and Mapping Soil Organic Carbon in Mali, West Africa Using Spatiotemporal Methods."

Querido's results include, among others: 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 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 does not seem to change dramatically with time.

Spatial Data Purchased and Ground-truthed for a Set of Six Fields Placed Under the ACN Technology and for which the Challenge was to Assess Soil C Change

Soil organic carbon measurement of fields and groups of fields needs a technology that is less costly and time-consuming than the traditional soil sampling and measurement of soil organic C. Preliminary imagery was obtained through a sister project "Carbon from Communities" funded by the National Aeronautics and Space Administration (NASA). This imagery was supplemented with selected imagery from each of the six sites in subsequent years: fields at Fansirakouro (2), Siguidolo, Sougoumba, Oumarbougou and Sikasso. The assessment provided a baseline for estimating regeneration and loss of trees in the fields as well as tree growth. The results indicated that the ACN technology is clearly visible and identifiable at the 60 cm resolution provided by the Quickbird imagery. This is important because it permits inventories of ACN to be performed using satellite imagery rather than dispatching a team to determine whether ACN has been maintained (Figure 1).

The ACN Technology was Evaluated as to How it Affected Crop Yields, Soil Water Content and Carbon Sequestration

Effects on Crop Yields

An ACN experiment was designed and implemented in The Gambia in 2003. This experiment introduced a new way to

Figure 1. High resolution, remotely sensed imagery, discussed with the village chief, appears to be sufficient to detect and monitor the presence of the ACN technology – the permanent ridges are easily detected. This greatly reduces costs of monitoring the technology.

Figure 2. Structure of an ACN in a field showing Ado (permanent ridge) (A) and annually drawn ridges (B).

conduct field experiments that included both small-scale field effects and watershed effects related to the interaction among fields. Experimental replications were placed on isolated segments of the watershed. The results (Doumbia et al. 2008) indicated a 24 percent increase in maize yield in the relatively high rainfall environment of The Gambia. As had been reported earlier, fertilizer use efficiency was improved as a result of both ensuring increased crop water. Fertilizer use efficiency was improved by 33 percent when the ACN technology was present.

Effects on Soil Water

With the assistance of a hydrologist from Virginia Tech a recent technology for rapidly and easily measuring soil water was installed on an experimental site in Siguidolo, Mali, (Figure 2). The Diviner® technology, which measures the capacitance of soil water was used and applied in a super-imposed experiment at Siguidolo, the site of the original ACN experiment. The hypothesis of the field study was that no difference existed in water content between two large plots under ACN and two that were not. Measurements were collected over four growing seasons every 2 to 4 days at 10 cm increments to a depth of 160cm. The data indicate that where the ACN was present, greater amounts of water were retained in the 0-160 cm depth than in the 0-80 cm than where the ACN technology was not applied. The results also demonstrated that there was a greater difference between ACN and no ACN in the 80-160 cm zone. In addition, the measurements indicated much greater deep drainage occurred (defined as the amount of water that descended past the 160 cm depth) where ACN was present. The latter result provides some explanation for the higher water table in drinking water wells in villages with ACN (Figure 3). These results also provide a rationale for the higher yields of food crops under ACN as well as higher levels of C sequestration due to increased crop growth and increased tree growth.

The Impacts of ACN Technology on Groundwater

The measurement of soil water content during the rainy season in ACN and non-ACN plots indicated, as discussed

Figure 3. Measurement of village drinking water wells, has proved to be important in assessing the watershed scale effects of the ACN technology.

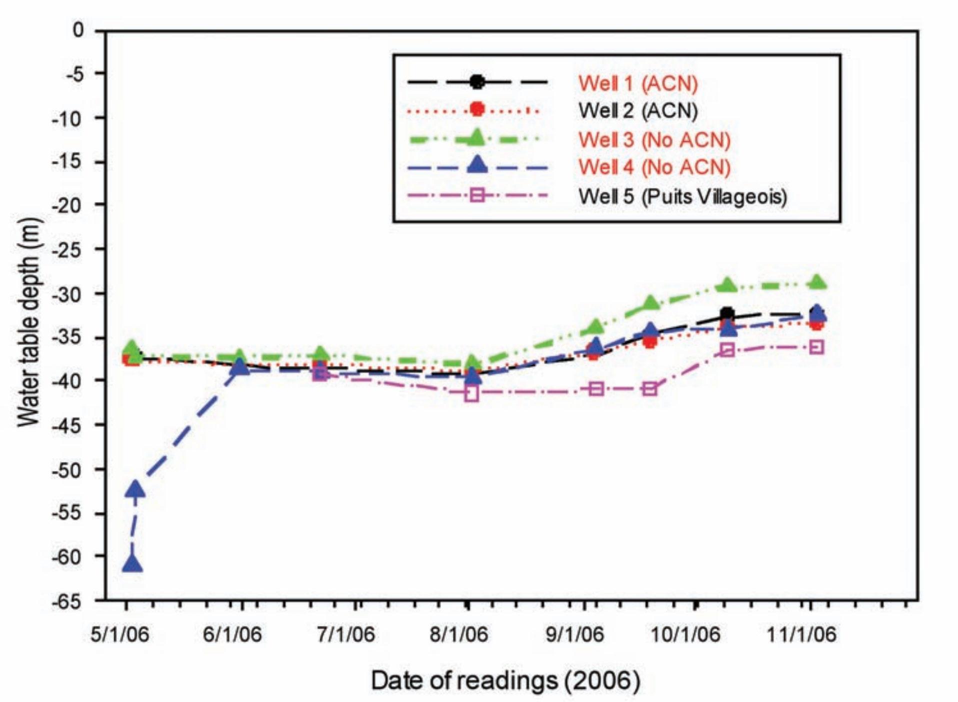


Figure 4. Well water depth 2006, Drissa Traore's field (4 wells) and one village well ('Puits Vilageois'), Fansirakouro, Mali.

above, that deeper drainage occurred where the ACN technology was in place in Siguidolo, Mali. In an effort to assess that this was, in fact, leading to increased amounts of ground water, a series of wells were dug to determine ground water levels. A matching well was dug in the village, which had no ACN, as a reference. The depth of water in the five wells (two wells in an ACN field, two in a field with no ACN, and a fifth well in the village) indicated that, during the 2007 - 2008 dry season, water remained in the wells in the ACN field, but the well in the village, as in previous years, went dry (Figure 4). The increase in groundwater increases the possibility of dry-season irrigation observed in 80 percent of the villages in Siguidolo, Mali. Additional monitoring of wells in the village of Fansirakouro and in one village with no ACN will be continued as long as possible.

Effects on Carbon Sequestration

At the beginning of this research in 2000, while it was well known that ACN increases crop yields, it was not clear that soil organic C would also be affected. The results of the study are that soil organic C was increased 26 percent in The Gambia, 12 percent in Siguidolo, Mali and by 14 percent in peanut systems in Senegal (Doumbia et al. 2008). As indicated previously the ACN system was modified from the original Mali version for Senegal and The Gambia to accommodate the local practice of planting on non-furrowed soil and then drawing small furrows after the crop is established. In Senegal, seven farms were selected for tests of ACN versus no-ACN beginning in 2004. Results obtained in 2006 indicated that soil organic carbon had increased by 270 kg/ha/yr on the peanut systems. The ACN system thus provides one of the few cropping systems that not only limits losses of soil organic C, but actually can increase soil organic C in the C-depleted soils of the Sahel. The significance of this only becomes clear when the essential role of soil organic C of providing nutrients, nutrient holding capacity, water holding capacity and its ability to sustain active microbial populations in soils of the Sahel is understood (Figure 5).

Figure 5. Preliminary results indicate that trees such as the shea butter tree (Vitellaria paradoxa) being measured here contribute sigificant amounts of C to the system, in part because they shed leaves each year.

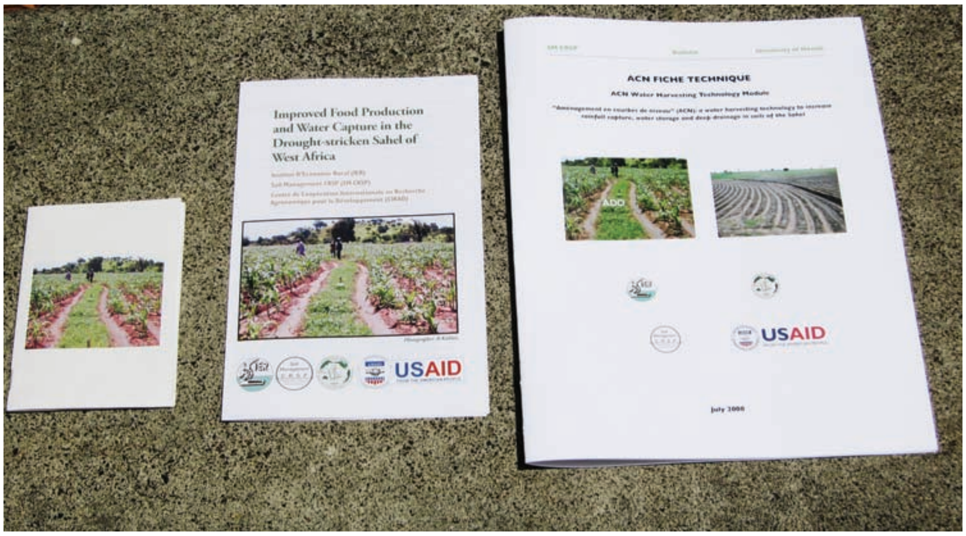


Figure 6. Three forms of dissemination literature produced for the spread of the ACN (Amenagement en courbes de niveau) technology. Right, the Guide to construction of the ACN as a "fiche technique" or extension bulletin. Center, a brochure both introducing the ACN and describing the benefits. Left, a completely visual Graphic Guide to ACN photobook that illustrates its application in maize and millet systems and the construction and maintenance.

Figure 7. Farmer Zan Diarra reviewing the Graphic Guide to ACN – a technology that was developed on his land and may have contributed to his current wealthy status.

Brochures, Training Publications and Scientific Publications of the ACN Technology were Prepared to Increase its Diffusion Throughout the West African Community

Publications in various forms were prepared for the dissemination of the ACN technology in both the scientific as well as the local communities. These publications included two that presented the scientific data describing the increase in soil water found associated with the ACN as well as the increase in soil organic C (Kablan et al. 2008; Doumbia et al. 2008) (Figure 6).

In addition a new type of publication was prepared to support the training and dissemination of the ACN technology. The publication is an attempt to describe the ACN survey and implementation in a completely graphic document – a document that can be viewed and understood without dependency on language or literacy. The small, 3 x 5, in folded publication will be called A Graphic Guide to ACN (Figures 6 and 7).

Survey Results Beginning in 2000 and Continuing Every Other Year (e.g., 2002, 2004, 2006) were Returned and Discussed with the Farmers at Each Site

The research and application information was communicated to the farmers who had shared their fields and land with the project during the latest five to as many as 10 years, in one case. This was the "restitution" or return of information to the farmers thus completing the process of 1) acquisition of information, including remote-sensing, soil sampling and interviewing, 2) processing of the information to draw conclusions, inferences and to test hypotheses related to cause and effect and due to association, and 3) restitution – or the return of the acquired, processed, and synthesized information back to the community and households that collaborated with the project.

The latter is a very important aspect of the "participation" aspect of our entire research often academics conduct surveys, collect data, and extract information, summarize and publish it for their own credit, advancement and benefit. Little goes back to those that contributed that information in the first place. For us, restitution is making sure that the original owners of the information derive some benefit from the extraction process. It is a focused attempt to return the original information with value-added – i.e., the results of the scientific interpretation of the results, the analysis of the results and anything else from the research process that might benefit the farmers and the community. We included this aspect of the research process for the first time, for us, in this project. At this point we feel strongly that it needs to be included in all research effort – it is an aspect of recognizing and respecting the intellectual property of those with whom we work.

LESSONS LEARNED

- Climate change has adversely affected West African food security in extreme ways, making life and livelihoods very difficult to impossible in some cases.
- Considerable potential exists to improve land management by means of improving the management of natural resources, namely the improved capture and use of the area's meager rainfall.
- Key to improving food security will be the development of human resources to carry out studies as they are recognized and supported. While adaptation and discovery of new techniques and procedures were results of the research, the greater benefit would be the new cadre of researchers and scientists created. We expect them to continue and to improve on the research supported by the concluded project.

NEXT STEPS

An association has been formed in Mali of project collaborators in an effort to stimulate and encourage a commercial application of the ACN technology. This association, Association pour le Renforcement de la Capacité Communitaire de Carbon (ARCCA), will continue to seek funding and support to find the means to encourage a wider implementation of the ACN technology. The SM CRSP Soil Sequestration Project has identified many advantages and benefits to the technology. It could be used to lessen the harmful effects of climate change. Moreover, the ACN technology provides an opportunity to: 1) reduce C in the atmosphere, 2) improve soil properties, and 3) move toward sustainable improvements in food security for West Africans.

Diviner reading by Richard Kablan, on left, and Yorote Abdramane of IER in ACN field, Fansiakoro, Mali.

PARTICIPATING AND COLLABORATING SCIENTISTS & INSTITUTIONS/ORGANIZATIONS

National Agricultural Research Systems (NARS)

Gambia

National Agricultural Research Institute (NARI)
Alieu Bittaye
Modou Faye
J. Fatajo
A. Jarju
Mamudu Jarju
Babou Jobe

Kenya

Tropical Soil Biology and Fertility Institut of CIAT (TSBF)
Andre Bationo

Mali

Institut d'Economie Rurale (IER)
B. Ballo
A. Berthé
Harouna Coulibaly
M. Doumbia
H. Konaré
Oumar Samake
M. Sissoko
S. Sissoko
Y. Toloba
Kalifa Traoré
M. Vaksman (CIRAD)
A. Yoroté

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

Institut de l'Environment et de Recherches Agricoles (INERA)
Boubié Vincent Bado

Niger

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT-Niamey)
Abdou Adamou

TRAINING AND DEGREE PROGRAMS

Degree Programs

Year	Name	Degree	Gender	Institution	Home Country
2003	Jocelyn Bajita-Locke	PhD	F	University of Hawaii	Philippines
2004	Xiu Fu Shuai	PhD	M	University of Hawaii	China
2005	Seriba Konaré	Ing	M	University of Bamako	Mali
2006	Souleymane Kanta Kiari	Ing	M	University of Bamako	Mali
2007	Hamidou Konare	PhD	M	University of Hawaii	Mali
2007	Aminata Sidibe-Diarra	PhD	F	University of Hawaii	Mali
2008	Antonio Querido	PhD	M	University of Hawaii	Carbo Verde

Non-Degree Programs

Name	Home Country	Gender	Dates
Ansumana Jarju	The Gambia	M	2007
Mondon Sene	Senegal	M	2003
Aminata Badiane	Senegal	F	1999
Aminata Badiane	Senegal	F	2002

Workshops

Title	Date	Location	Gender
Carbon	March 2004	Mali	25M
Carbon	7/12-17/04	Bamako, Mali	19M,1F
Carbon	1/17-22/05	Banjul, Gambia	18M,1F
Carbon	2005	Mali	5M
Carbon (Evaluation panel)	2/21-24/06	Bamako,Mali	24M,1F
Carbon	2/19-22/07	Bamako,Mali	49M,1F
Carbon	2007	Gambia	14M,1F

PUBLICATIONS, PRESENTATIONS AND REPORTS

Journal Series and Books

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.

Doumbia, M., Ansumana Jarju, Modou Sène, Kalifa Traoré, Russell Yost, Richard Kablan, Kevin Brannan, Abou Berthe, Charles Yamoah, Antonio Querido, Pierre C.S. Traoré and Abdou Ballo. 2008. Sequestration of organic carbon in West African soils by Aménagement en Courbes de Niveau. Agronomy for Sustainable Development 28 (Electronic Publication, September 2008).

Kablan, R., R.S. Yost, K. Brannan, M. Doumbia, K. Traore, A. Yorote, Y. Toloba, S. Sissoo, O. Samake, M. Vaksman, L. Dioni and M. Sissoko, 2008 "Amenagement en courbes de niveau", increasing rainfall capture, storage, and drainage in soils of Mali. Arid Lands Research and Management 22:62-80.

Kablan, R., R.S. Yost, K. Brannan, M. Doumbia, K. Traoré, A. Yoroté, Y. Toloba, S. Sissoo, O. Samaké, M. Vaksman, L. Dioni and M. Sissoko. 2008. ACN Fiche Technique, ACN Water Harvesting Technology Module. "Amenagement en courbes de niveau", ACN: a water harvesting technology to increase rainfall capture, water storage, and deep drainage in soils of the Sahel. SM CRSP Bulletin, July, 2008.

Shuai, Xiufu and R. S. Yost. 2004. State-Space Modeling to Simplify Soil Phosphorus Fractionation. Soil Sci. Soc. Am. J. 68:1437-1444.

Traoré, K.B., G. McCarthy, J.S. Gigou, M.D. Doumbia, A. Bagayoko, R.S. Yost, H. Konaré, L. Dioni, H. Coulibaly, A. Sidibe et R.A. Kablan. 2002. Aménagement en courbes de niveau et conservation du carbone. Paper presented at CIRAD Conference on Soil Carbon, Montpellier, France, September 23, 2002.

Yost, R., P. Doraiswamy and M. Doumbia. 2002. Defining the contract area: Using spatial variation in land, cropping systems, and soil organic carbon. *In:* A Soil Carbon Accounting System and Management System for Emissions Trading. A Special Publication of the Soil Management Collaborative Research Support Program, Honolulu, HI.

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.
(Photo: R. Yost)

Chapter Six

Carbon Sequestration

MEASURING AND ASSESSING SOIL CARBON SEQUESTRATION BY AGRICULTURAL SYSTEMS IN DEVELOPING COUNTRIES - WEST AFRICA

JAMES W. JONES, AGRICULTURAL AND BIOLOGICAL ENGINEERING DEPARTMENT
UNIVERSITY OF FLORIDA, GAINESVILLE, FL, USA

UNIVERSITY OF FLORIDA

Maize residue left as mulch on the soil surface. In the Northern Savannah zone of Ghana, on-station and on-farm studies have demonstrated that practices that return all or most crop residues to the soil maintain higher soil C levels than current practices.

Table of Contents

OVERVIEW & EXECUTIVE SUMMARY

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 farming communities in developing countries the incentives they need to increase and sustain productivity of the land. However, farmers must be sure that their livelihoods will be enhanced before they would consider changing their management practices to increase soil carbon levels. Little research has been done to determine practical management systems that will increase soil carbon in West Africa where soils are sandy and low in organic matter, temperatures are high and rainfall is highly variable, use of inorganic fertilizer is very low, and farmers rely on their own production for their livelihoods. Furthermore, carbon purchasers and traders need assurances that contract levels of carbon are being achieved before they would invest in a contract for carbon sequestration. Accurately monitoring carbon in soils is highly problematic and no practical and reliable soil carbon monitoring system exists.

Our research, carried out in Ghana and Mali, focused on developing Carbon Enhancing Management Systems (CEMS) that would be sustainable, practical, economically viable and increase soil carbon at rates that could lead to opportunities for farming communities in this region to participate in the carbon market. Additionally, our research developed and evaluated a method for monitoring soil carbon changes on farms in an area about 100 square kilometers, scaling up values across many fields.

Objectives for Phase 2 were:

1. Develop Practical Methods to Measure Gains and Losses of Soil Organic C Over Time in Spatially Variable Soils in West Africa.
2. Assess the Potential for Soil C Sequestration for Selected Sites in West Africa.

The latter was a new objective for Phase 2 of the Soil Carbon Sequestration project of the SM CRSP.

PHASE 2 PROJECT ACCOMPLISHMENTS

- We determined that soil carbon decreases rapidly under high temperatures and sandy soils in Ghana after clearing native vegetation and farming for 4-5 years when traditional subsistence, slash and burn practices are used. Adding small amounts of fertilizer, retaining much of the crop residue on the fields, and using minimum tillage helped reverse the trend and maintained soil carbon at values higher than traditional practices and, for some of the options tested, maintained carbon near the levels under native grasses and bush. These studies were based on on-farm as well as station research. Bulletins were written for extension, NGOs, and governmental ministry staff to encourage the adoption of CEMS practices in Ghana.
- We showed that the potential for soil carbon sequestration varied across fields, depending on crop, soil texture and residue management. Using data from over 130 farmers' fields in northern Ghana and practical CEMS, we estimated that the average soil carbon sequestration potential is about 3.5 Mg of carbon per hectare over a 20 year period, which was about 375 Mg of carbon (or 1,670 Mg CO_2), an amount that would be attractive to carbon traders if it could be verified.
- A number of CEMS practices were identified that would increase profits, stability of production and soil carbon. These practices included a combination of crop rotations of cereals with legumes and native vegetation as well as small doses of fertilizer, use of available manure and retaining some residue in the field, taking into account farm labor availability and fodder requirements for animals.
- A new method was developed for measuring gains and losses of soil carbon in agricultural fields. This method combines some field sampling with soil carbon simulation models, taking into account the uncertainties in both. We showed that uncertainties in soil carbon measurements alone can be reduced by as much as 75 percent using this new data assimilation method. This method also allows one to determine soil sampling frequencies over time and space needed to achieve a prescribed level of uncertainty.
- High resolution remote sensing technology was developed to identify crops and trees in farmers' fields for use in monitoring carbon in both soils and trees. Individual trees in fields and their diameters and heights are determined from a satellite image, that covers about 100 square kilometers in area. Carbon stored in trees can also be estimated from these images. A combined soil and tree carbon monitoring system has been developed to enable accounting for both crops and trees grown in agricultural fields.

- A cropping system model was improved for use in predicting crop productivity and soil carbon in soils and farming systems of West Africa. A component was added to account for soils with low phosphorus levels in addition to low nitrogen and carbon. This model was evaluated using experiments in both northern and southern Ghana. A simple soil carbon model was developed by reducing a more complex one and tested for use in the new monitoring method.

HIGHLIGHTS OF ACCOMPLISHMENTS

1. Integrated Protocol for Measuring Gains and Losses of Soil Carbon

The first output for Objective 1 was an integrated protocol for measuring the gains and losses of soil C under agricultural systems incorporating sampling, prediction and remote sensing technologies. This was important for several reasons. First, field samples are needed for measuring soil carbon, and sampling measurement of soil carbon in the lab are expensive and time consuming. It would not be practical to visit every field to make measurements of carbon in a contract. Furthermore, these measurements have large uncertainties in derived estimates of soil carbon. Errors in measurements are much larger than changes in soil carbon that would occur over several years. In other fields, such as hydrology, climate,and engineering, methods have been developed to reduce measurement uncertainty by combining actual measurements with dynamic models that predict changes, usually referred to as data assimilation. We adapted one of these methods, the Ensemble Kalman Filter (EnKF), that incorporates soil C measurements with a soil carbon model, taking into account the uncertainties of both. The EnKF was used to demonstrate soil carbon monitoring over a 20-year time period, providing annual values of carbon sequestration and the uncertainty associated with those values. A widely-used soil C model (RothC) was analyzed and simplified for efficient use with this method when monitoring many fields over large areas. A method was also developed to monitor tree height and crown area growth using high resolution remote sensing for use in predicting tree carbon mass (Figure 1). These components are designed for use in an integrated protocol that includes soil and tree carbon models, *in situ* soil sampling, and a soil C model for monitoring C sequestration in agricultural fields with sparsely spaced trees, which is common in West Africa (Figure 2). They have been tested under experimental conditions and are at a level of development that could be incorporated into a prototype carbon sequestration project for evaluation.

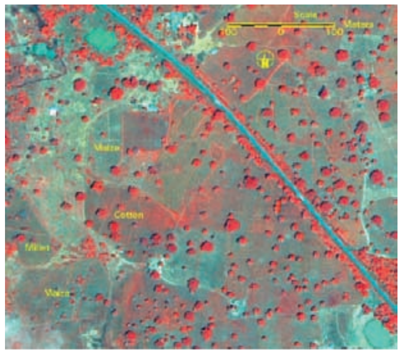


Figure 1. Quickbird high resolution satellite image of farm fields with trees in Oumarbougou, Mali Oct. 11, 2002.

2. Predictive Tools for Evaluating Soil C Sequestration Options at Farm Field Scales

The second output for Objective 1 was to improve 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. A field-scale dynamic soil and cropping system model was improved and adapted to West African smallholder agricultural systems. One focus of model improvement was in the soil C module to more accurately account for the poor soils, harsh climate, and farming practices of this region. An experiment was conducted to develop a relationship between soil water content and soil organic matter decomposition rate. In addition to using data from the literature, data from an 11-year crop-

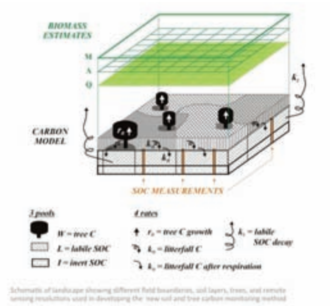


Figure 2. Schematic of landscape showing different field boundaries, soil layers, trees, and remote sensing resolutions used in developing the new soil and tree carbon monitoring method.

ping system experiment in Burkina Faso was used to develop an improved method to initialize soil C pools to more accurately describe carbon characteristics in degraded as well as relatively fertile soils. This is needed in order to use these tools to estimate crop productivity and soil C dynamics for different management options. Also, a component was added to the DSSAT crop models to predict soil phosphorus (P) dynamics and the effects of soil P management on crop productivity and on soil C dynamics. Two experiments in Ghana, one in P-deficient soil and the other in a

Figure 3. Maize without fertilizer averaged about 0.5 t/ha in the 5-year Wa, Ghana experiments for model development.

Figure 4. Fertilized maize crop in Wa, Ghana averaged about 3.7 t/ha in the Wa, Ghana experiment for model development.

Figure 5. Maize growth following bare soil minor rainy season treatment during the fourth year was very low and produced only 0.1 t/ha grain yield in Kpeve, Ghana 2006.

soil with adequate P levels, were conducted and used to develop this model and to demonstrate its ability to simulate responses for a wide range of P availabilities (Figures 3 & 4).

3. Carbon Enhancing Management Systems (CEMS) Practices

For Objective 2, the first output was a demonstrated capacity of land use cropping systems to sequester C in soils in West Africa under different rainfall regimes. In a four-year experiment in savannah-forest transition zone in the Volta Region of southern Ghana, six different maize-based cropping systems were evaluated to represent practical options for farmers in this area, and a seventh treatment was included to measure soil C and maize yield responses in a field that was poorly managed (no nutrient inputs, removal of all crop residues, and prevention of fallow growth after maize harvest each year). This experiment clearly demonstrated the fragility of this soil if it is mismanaged for as few as three or four years in this climate (Figures 5 & 6). Maize production failed after three years, soil C declined by over 50 percent, and microbial activity was considerably reduced. The study also showed that relatively high maize yields in the major rainy season (1 to 2 t/ha) could be sustained by growing legumes or native vegetation during the minor rainy season and keeping organic matter residue on the soil with no inorganic fertilizer inputs; higher yields

Figure 6. Pigeon pea growth during the minor rainy season was high and produced large amounts of organic matter that maintained a yield of about 1.5 t/ha after four years in Kpeve.

were obtained if inorganic fertilizer was applied. A study of microbial diversity in these treatments showed that the proteibacterial population can be used to indicate the changes in level of C stored in soils. In the Northern Savannah zone of Ghana, on-station and on-farm studies demonstrated that practices that return all or most crop residues to the soil maintain higher soil C levels than current practices, which usually involve burning of residue. In all experiments, soil C levels for all treatments were lower than undisturbed soils and had native vegetation growing in the fields. Furthermore, the studies demonstrated that several cropping systems with little or no tillage were effective as practical soil carbon enhancing management practices. Three bulletins were written and distributed to extension and ministry of agriculture staff in Ghana to use to encourage the adoption of CEMS practices.

4. Potential Soil Carbon Sequestration in West Africa at Community Scales

The second output for Objective 2 was an assessment of the potential for soil C sequestration for selected sites in West Africa at scales necessary for C trading. Field surveys of over 250 fields (approximately 250 ha) in northern and southern Ghana were conducted to quantify the soil textures, soil carbon levels in the top 20 cm of soil, and cropping histories (Figure 7). Most fields sampled were sandy and contained very low levels of C, particularly in northern Ghana where soil C levels were mostly between 0.4 and 0.6 g/kg. The proportion of farmers' fields left in fallow decreased by about one-half between 2001 and 2005 (from about 44 to 20 percent), which shows the increasing pressure on the land for producing crops. Soil C and texture were highly correlated. This correlation along with a spatial analysis was used to compute soil C across the landscape using co-kriging. The field survey of 132 fields in Northern Ghana was used to scale up output from the Ensemble Kalman Filter (EnKF) to demonstrate its use in a hypothetical carbon project for monitoring soil C sequestration over a 20 year period, aggregated to a community scale. When compared with the use of sampling and spatial aggregation each year to monitor soil C in this study, the EnKF had lower uncertainties throughout the time period and provided more accurate estimates for the first five years. The potential for soil C sequestration in the top 20 cm of soil averaged over the 132 fields was estimated to be about 173 kg/ha/yr per field over the 20 year time period. The highest single field C sequestration value averaged about 286 kg/ha over the 20 years. These estimates are conservative, taking into account the spatial variability of fields, the use of typical crop rotations, using minimum tillage, from 20 to 40 kg/ha of nitrogen application for cereal crops, retaining 75 percent of crop residue in the fields, and initial conditions that reflect the current landscape management and soil C levels (Figure 8). Aggregated 20-year C sequestration estimated for this 132 ha study was about 375 Mg of C (or about 1,670 Mg CO_2, an amount that could be considered in a contract by carbon traders).

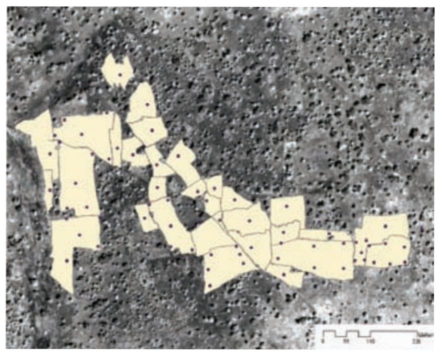


Figure 7. High resolution remote sensing images showing some of the 2004 georeferenced sample sites for measuring soil carbon in the Kparisaga Village near Wa, Ghana.

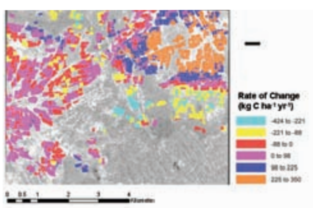


Figure 8. Estimated rates of soil C change for fields simulated to be under Carbon Enhanced Management Systems near Wa, Ghana (J. Koo, 2007). Higher rates of change in soil C in the upper right section of the figure were associated with better soils (less sand).

5. Economic Benefits of CEMS to Farmers

A case study in Wa, Upper West Region of Ghana was used to test 48 different cropping strategies by means of a crop simulation model and a household-level multiple-criteria optimization model. The 4.8 ha household, based on an intensive farm survey, included livestock, crop production, labor, land, and economic characteristics (Figure 9). The 48 cropping system options were simulated using the adapted DSSAT model to quantify yield and soil C changes for each of the household's fields for each management practice. 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 field level, and by its contribution to the farm income with and without carbon payments. In general terms, as the management intensified with higher levels of fertilizer and pesticide applied to the crops and higher proportions of residue returned to the soil, the levels of soil C increased, while concomitantly yielding higher economic returns than the baseline levels, even in the absence of carbon payments. The contribution of carbon to household income was significant, about 10 percent of farm profits. However, in the Northern Ghana region those management practices that generate 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. 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. Considering that the smallholder farmers are very diverse in terms of their available resources, access to credit, livelihood strategies and risk attitude, it is unlikely that a pro-carbon strategy will fit all. This analysis identified different strategies able to be adopted by different farmer groups. Inexpensive strategies might be adopted by poor farmers, while management practices branded as very expensive may be of interest to market-orientated farmers willing to invest in higher return strategies. These farm-level results are site specific, and the conclusions regarding the management strategies identified as best options would not be directly transferable to other regions. However, the approach used in this study can be adopted for use in other regions where soil C sequestration is being considered (Naab et al. 2008a).

Figure 9. An interview with a farmer in the Nakor village near Wa, Ghana for the case study used to study the feasibility of farmers adapting Carbon Enhancing Management Systems.

LESSONS LEARNED AND NEXT STEPS

Development and testing of Carbon Enhancing Management Systems and the soil carbon monitoring system has led to the following lessons learned and opportunities for future research:

- Carbon in soils is highly volatile in West Africa. Carbon built up as soil organic matter during native vegetation fallow periods may be lost in as few as four to eight years after clearing the land and growing crops using poor management practices. During this short period of time, soil carbon can drop by over 50 percent of the values measured at the end of fallow periods. This means that crop production will drop very quickly (within three years in one study in southern Ghana) as soil carbon drops to a new stable level that decomposes too slowly to mineralize enough nutrients to support crop growth. Although this process is well known, our research highlighted the fragility of soils in this region and the critical importance of good soil management practices for producing crops and sequestering carbon.
- Farmers in this region can gain economic benefits by adopting CEMS, from better and more stable yields relative to existing practices as well as from payments for carbon sequestration. Economic benefits associated with increased and more stable yields were greater when com-

pared with payments for carbon sequestration. This raises questions about farmer adoption of CEMS even without carbon sequestration payments. These practices include application of small amounts of fertilizer, keeping some of the crop residue on fields, and limited tillage. In Ghana, use of fertilizer is increasing, but it seems that it is still unavailable to many farmers and some indicated that their unwillingness to use fertilizer is due to risks of inadequate rainfall. More labor would also be required for some CEMS, and if sufficient land is available for farmers to rotate crops with native vegetation fallow for sufficiently long periods needed to restore organic matter, many are likely to continue to resist change. If payments for carbon sequestration could be used to provide insurance or in some other way reduce risks of losses and improve farmer well-being, we believe that this would provide benefits to farmers and reduce land degradation in this region.

- Methods were developed to significantly reduce uncertainty in monitoring carbon in soil and trees, and also reduce costs. We learned that relatively simple models can be used along with soil sampling and remote sensing methods to reduce uncertainty in monitoring soil and tree carbon in agricultural systems. We have received inquiries from carbon traders and environmental monitoring firms about implementing this technology on a trial basis in the USA. Next steps should be to evaluate this method in selected areas in the USA and to work with carbon and environmental firms to determine refinements needed to operationalize this technology. Proposals are being written to further advance the methodology as well as to transfer it to the carbon resources management community for use.
- Three bulletins on the CEMS were written and provided to extension agents, NGOs, and ministries of agriculture and environment in Ghana (Adiku et al. 2008; Naab et al. 2008a; Naab et al. 2008b) bulletins provide information for these agencies to use to explain to farmers the importance of soil management practices for sustaining yield and increasing soil organic matter and carbon, to introduce the agricultural community to the concepts of carbon sequestration, and to explain the economic benefits of those practices. These bulletins should be used to communicate with all important decision and policy makers that may help the farming communities adopt sustainable soil management practices, and look for ways to mobile resources to help overcome the constraints to farmer adoption of those practices, including opportunities to participate in the growing global carbon market.

Maize growth in elephant grass residue, Ghana.

PARTICIPATING AND COLLABORATING SCIENTISTS & INSTITUTIONS/ORGANIZATIONS

National Agricultural Research Systems (NARS)

Ghana

Savana Agricultural Research Institute (SARI)
Jesse Naab

University of Ghana
Samuel Adiku
Stella Assuming-Brempong
Gabriel Dowuona
N.K. Amon
Stephen Narh

Mali

Institut d'Economie Rurale (IER)
Mamadou Doumbia

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

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

United States

Montana State University
John Antle

University of Florida
Kenneth Boote
W. McNair Bostick (deceased)
Samira Daroub
Kofikuma Dzotsi
Arjan J. Gijsman
Jianqiang He
Shrikant Jagtap
James W. Jones
Jawoo Koo
Valerie K. Walen

University of Hawaii
Russell Yost

International Agricultural Research Centers (IARC)

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

TRAINING AND DEGREE PROGRAMS

Degree Programs

Year	Name	Degree	Gender	Institution	HomeCountry
2004	Souleymane Kanta Kiari	Ing	M	University of Bamako	Mali
2005	Seriba Konaré	Ing.	M	University of Bamako	Mali
2005	Welch Bostick	PhD	M	Florida University	USA
2006	Valerie Walen	MSC	F	Florida University	USA
2007	Jawoo Koo	PhD	M	Florida University	S. Korea
2007	N.K. Amon	MSc	F	University of Ghana	Ghana
2007	Stephen Narh	MSc	M	University of Ghana	Ghana
2008	Kofikuma Dzotsi	MSc	M	Florida University	Togo
2008	Daniel Darko	MSc	M	University of Ghana	Ghana
2008	Pierre C. Sibiry Traoré	PhD	M	Sherbrooke University (Canada)	Mali

Workshops

Title	Date	Location	Gender
Training Program on Application of Crop-Soil Models	May 1-21, 2008	Griffin,GA	43M,15F
Training Program on Application of Crop-Soil Models	May 2004	Griffin,GA	34M,8F
Training Program on Application of DSSAT Models	Aug 2004	Arusha, Tanzania	26M,5F
Training Program on Application of DSSAT Models	Oct 2005	Accra,Ghana	28M,6F
Training Porgram on TOA and DSSAT Models	Feb 2006	Accra,Ghana	12M,3F
Training Program on DSSAT Application	June 2007	Mombasa, Kenya	15M,3F

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Chapter Seven

Carbon Sequestration

MEASURING AND ASSESSING SOIL CARBON SEQUESTRATION BY AGRICULTURAL SYSTEMS IN DEVELOPING COUNTRIES - SOUTH ASIA

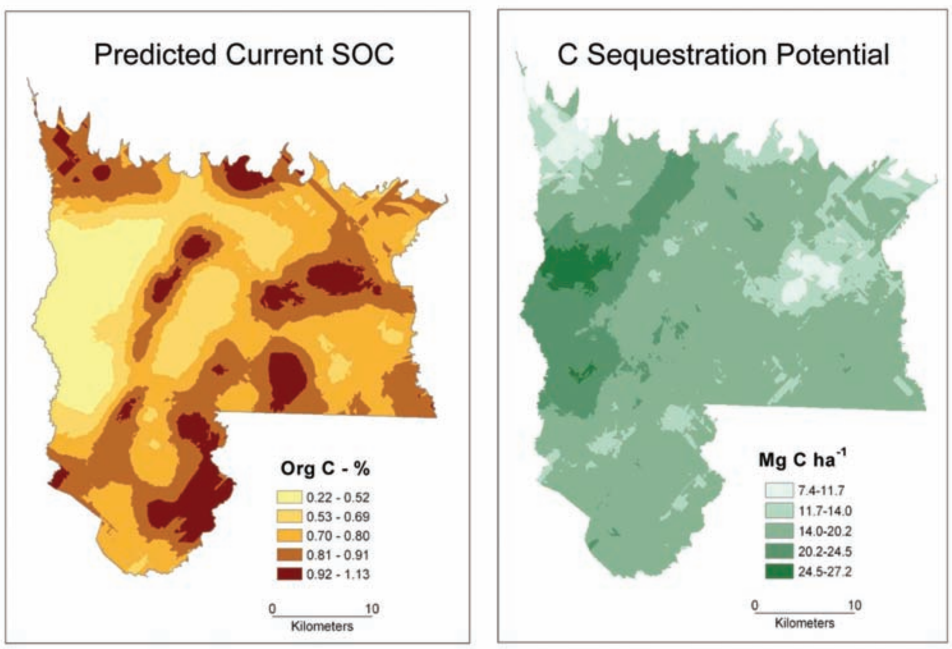
JOHN M. DUXBURY, DEPARTMENT OF CROP AND SOIL SCIENCES
CORNELL UNIVERSITY, ITHACA, NY, USA

JULIE G. LAUREN, DEPARTMENT OF CROP AND SOIL SCIENCES
CORNELL UNIVERSITY, ITHACA, NY, USA

CORNELL UNIVERSITY

Farmer viewing surface seeded wheat field in Rupandehi district, Nepal. (Photo: J. Duxbury)

Table of Contents



OVERVIEW & EXECUTIVE SUMMARY

This report summarizes six years of research by Cornell University under the SM CRSP focusing on carbon sequestration in soils under the rice-wheat cropping pattern in the eastern Gangetic plain in Nepal and Bangladesh. Interest in carbon sequestration in soils has become very high in recent years as a strategy to mitigate anthropogenic greenhouse gas emissions and to improve agricultural sustainability as higher soil organic carbon (SOC) levels improve soil physical condition and fertility. Soils of the rice-wheat cropping system are the most carbon and physically degraded in the world because of the intensive wet tillage (puddling) used for flooded (paddy) rice (Figure 1). This puddling breaks aggregates protecting organic matter and is followed by aerobic conditions for wheat and other upland crops that enhance biological decomposition processes. The soils are mostly fine textured and hence have high potential to sequester carbon.

The Cornell SM CRSP Carbon Sequestration program collaborated with the Rice-Wheat consortium for the Indo-Gangetic Plains – the International Center for Maize and Wheat (CIMMYT) – and national government institutions and universities in Nepal and Bangladesh. Program activities focused on:

Figure 1. Wet-tilling (puddling) soil with a Chinese hand tractor. (Photo: P. Hobbs)

- Methods for determination of SOC;
- Characterization of the potential for SOC sequestration;
- Quantification of the impact of various management practices on SOC sequestration, especially reduced tillage; and
- Development of practical approaches to reduced tillage for the small, resource poor farmers that dominate the region.

Objectives for Phase 2 were:

1. Develop Practical Methods to Measure Gains and Losses of Soil Organic C Over Time in Spatially Variable Soils in South Asia.
2. Apply Methods to Assess the Potential for Soil C Sequestration for Selected Sites in South Asia.

PHASE 2 PROJECT ACCOMPLISHMENTS

- Improved the capacity of NARES in Nepal for measurement of SOC and soil texture.
- Established minimum and maximum SOC stocks as a function of soil texture for soils in native forest and rice-wheat cropping with conventional tillage practices.
- Showed that cultivation of soils for rice-wheat cropping reduced SOC stocks by an average of 20.7 Mg C/ha, or 39 percent, compared to native forest, and that loss of SOC was generally restricted to the 0-30 cm soil depth.
- Estimated that the maximum C sequestration potential for rice-wheat soils ranged from 8.2 to 33.8 Mg C/ha for soils containing 25 % and 100 % silt + clay, respectively; and showed that this ranged from 7 to 27 Mg C/ha with an average of 17 Mg C/ha for soils in the Rupandehi district, Nepal.
- Demonstrated that the effectiveness of different management practices for increasing SOC stocks in soils under rice-wheat cropping followed the order no-tillage = animal manure at 8-12 Mg dry matter/ha/y (a non-achievable rate) > stopping wet tillage (puddling) for rice > straw residue return > fertilization to increase crop productivity.
- Developed a simple 2-pool SOC model with a tillage factor for modeling SOC dynamics in rice-wheat soils – to address problems encountered with RothC (over-predicts equilibrium SOC levels and time to equilibrium) and CENTURY (under-predicts SOC) models.

- Examples of model predictions of equilibrium SOC gains were:
  - 4 Mg C/ha for cessation of wet tillage (puddling) for rice and 9 Mg C/ha for adoption of no-tillage, increasing up to 11 Mg C/ha with achievable inputs of straw and manure, in a soil containing 80% silt+clay;
  - a progressively greater rate of SOC gain on adoption of no-tillage as silt+clay content increases, e.g., a gain from 3.5 to 10 to 24 Mg C/ha as silt+clay content increases from 40 to 80 to 100%, respectively.
- Demonstrated that broadcast surface seeding is a viable, low technology approach for small, resource poor farmers to adopt no-tillage in a rice-wheat cropping systems provided that mulch is applied.
- Demonstrated annual SOC gains of 0.8 to1.1 Mg C/ha over a four to five year period for permanent raised beds on a sandy loam soil, coupled with higher yields, reduced water inputs, increased N response, reduced production cost and greater economic returns than conventional practices. Extended the raised bed technology to 900 farmers in Natore district, Bangladesh, using farmer to farmer dissemination methods.

HIGHLIGHTS OF ACCOMPLISHMENTS

A simple conceptual model, shown in Figure 2, was developed to describe the SOC content of rice-wheat soils. The three fundamental principles captured in this model for the tropical Gangetic plain environment were:

1. Soil aggregation is the primary variable controlling SOC levels that increase with silt+clay content.
2. Intensive tillage of soils destroys macro-aggregates, leading to the loss of physically protected SOC, leaving only SOC associated with stable micro-aggregates.
3. Non-protected C introduced through crop residues does not contribute significantly to SOC because of rapid decomposition.

Figure 2 shows boundaries for an upper limit of SOC that is associated with the native forest ecosystem and a lower limit which represents highly C degraded rice-wheat soils. The difference between the two boundary lines represents the manageable range of SOC, with reduction in tillage being the primary management tool. Soil in a given farmer field would be somewhere between the two lines (e.g., point

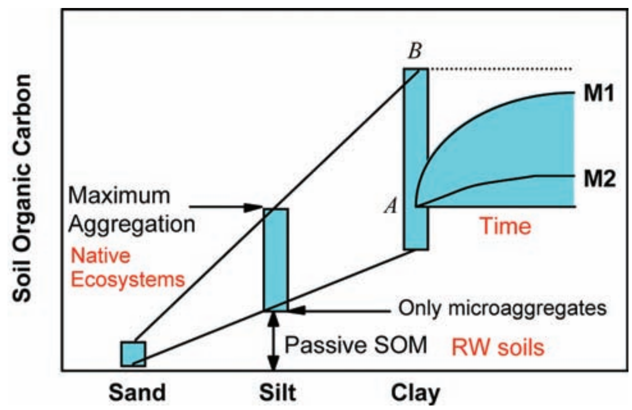


Figure 2. Conceptual model for the effects of tillage and soil texture on soil organic carbon content.

A) and adoption of reduced-tillage practices would lead to SOC gains commensurate with the extent of tillage reduction (e.g., M1 and M2).

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

Estimation of SOC stocks requires accurate measurements of soil OC content, texture and bulk density. We found difficulties with existing measurements of both OC and texture parameters in Nepal. Lack of reliable electricity, old equipment, inadequately trained technical staff, poor implementation of analytical methods and lack of quality control in analytical protocols were all factors that contributed to unreliable measurements. The dry combustion method of measuring SOC, which is widely considered to be the best method, was not available in Nepal and Bangladesh, where the Walkley-Black (W-B) strong acid digestion method was used. With training, research staff in Nepal generated W-B data that agreed well with our combustion data. We introduced loss on heating for 4h at 400°C as a simpler method of measuring SOC without the need for caustic chemicals. Figure 3 shows that this could work well but data quality proved to be inconsistent over time with turnover of laboratory staff. We also found errors in soil texture measurement due to incomplete dispersion of soils. This problem was corrected and national scientists revised their methodology.

Unfortunately, the SOC and texture measurement issues in Nepal and a general lack of soil bulk density data prevented

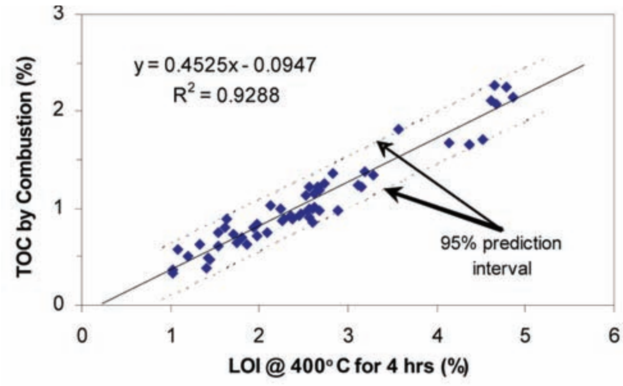


Figure 3. Comparison of SOC measured by dry combustion (Cornell) and loss on ignition (LOI), NARC, Nepal.

use of existing data sets in carbon sequestration analyses, causing us to generate our own data.

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

Measured SOC contents of farmer rice-wheat and forested sites generally increased as soil texture became finer, but as shown in Figure 4, considerable "noise" was found in the SOC-texture relationship. The SOC stock in the top 15 cm of rice-wheat soils varied by as much as 20 Mg C/ha for finer textured soils. The data envelopes and regression lines for SOC stocks in the 0-60 cm depth for rice-wheat and forest sites are shown in Figure 5. Figure 6 shows mean SOC stocks as a function of depth for rice-wheat and forest sites.

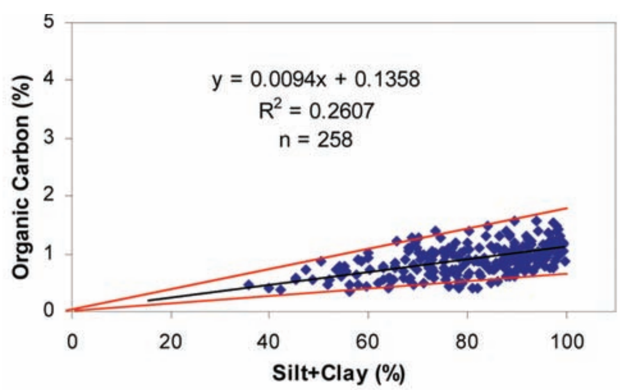


Figure 4. Mean regression line and data envelope for soil organic content in surface soil (0-15 cm) of farmer rice-wheat sites in Bangladesh and Nepal.

Measured mean SOC stock for the 0-60 cm depth was 11.1 Mg C/ha higher for forest than rice-wheat sites. The mean soil texture for forest sites, however, was sandier than that for rice-wheat sites and adjustment of the forest data to the mean texture for the rice-wheat sites for each depth increment is needed to make an accurate comparison. This adjustment increased the overall mean difference from rice-wheat sites to 20.7 Mg C/ha, which represents the mean potential for SOC sequestration for the study regions.

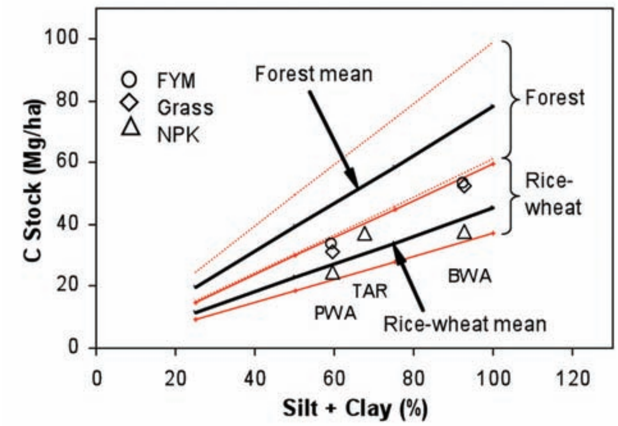


Figure 5. Measured effect of soil texture on SOC stocks (0-60cm) for forest and rice-wheat soils in Nepal and Bangladesh. Point data are for long-term soil fertility experiments at Parwanipur (PWA), Tarahara (TAR) and Bhairahawa (BWA), Nepal. Solid and dashed red lines represent the data envelope observed for RW and forest soils, respectively.

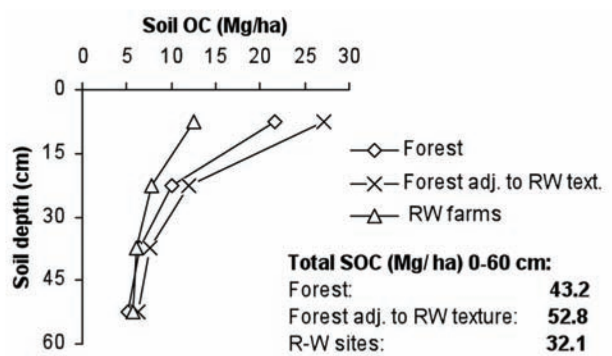


Figure 6. Mean organic carbon stock for successive 15 cm depth increments in soils from native forest and cultivated rice-wheat sites in Bangladesh and Nepal.

Table 1. Effect of soil texture on mean carbon sequestration potential (0-60 cm) for rice-wheat.

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

Table 1 shows the effect of soil texture on mean SOC sequestration potentials for rice wheat soils. Overall, rice-wheat cropping had reduced SOC stocks by an average of 39 percent.

Figure 7 shows a spatial prediction of SOC sequestration potentials for rice-wheat soils in Rupandehi district, Nepal based on soil texture and differences between current SOC stocks and projected values for the native forest for 300 data points. SOC sequestration potential ranged from 7 to 27 Mg C/ha and averaged 17 Mg C/ha.

The effect of different management practices on SOC stocks in rice-wheat soils was assessed in research experiments carried out by national scientists in Nepal and Bangladesh. The experiments ranged from medium (5-7y) to long-term (23-25y), with the former initiated by the SM CRSP program and the latter by the Nepal national research system. The management practices were a change to no-tillage (flat and permanent raised beds), return of crop residues (straw), addition of animal manure and increased crop productivity through fertilization. Table 2 shows that the effectiveness of the different practices at increasing SOC stock followed the order no-tillage = animal manure at 8-12 Mg dry matter/ha/y > straw residue return > fertilization to increase crop productivity. Somewhat surprisingly, given the light texture at the study sites, the permanent raised beds, where the only disturbance is annual reshaping, was the most effective practice, increasing SOC stock by 0.8-1.1 Mg C/ha/y over a five year period. Stopping intensive wet-tillage (puddling) for rice led to a SOC gain of almost 0.4 Mg C/ha/y over a seven year period, whereas return of crop residues led to gains of about half that amount. In most cases, we found that an experimental period of five years is needed before the relatively small increases in SOC stock could be measured.

Long-term (23-25y) fertilization of crops in Nepal, while substantially affecting crop productivity, had little impact on SOC stock. A gain in SOC stock was measured at only one of three sites, where P deficiency severely limited crop growth without fertilization. Except for 15-20 cm of stubble, crop residues were removed in these experiments. In contrast, manure addition at the rate of 8 Mg dry matter/ha/y increased SOC stocks considerably. However, this rate of addition, which we judge to be derived from 17.6 Mg straw feed or 150 percent of actual straw yield/ha/y, could not be achieved at a landscape scale. Simply stopping tillage, as measured in natural grass fallow areas that had been cultivated prior to the beginning of the experiments, gave the same SOC gain as the manure addition, demonstrating that no-tillage is the best practice to follow for increasing SOC stock.

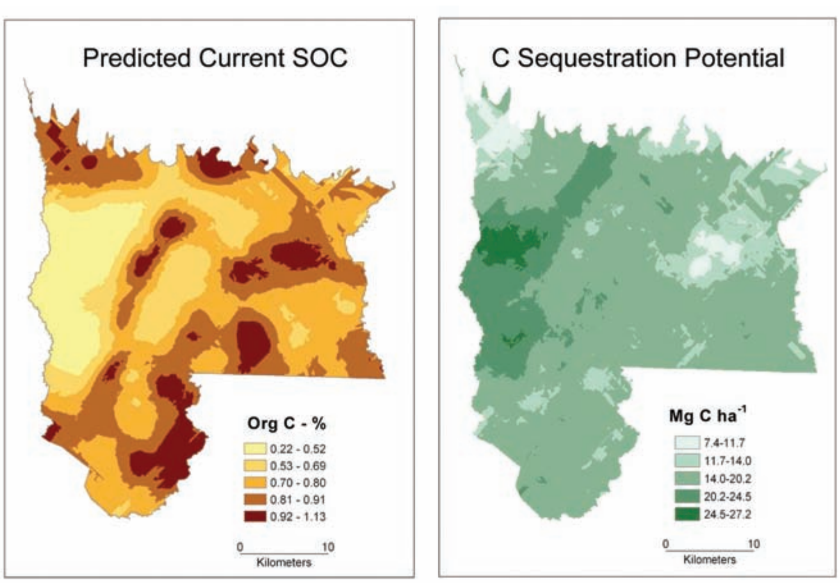


Figure 7. Predicted current soil organic C content and sequestration potential for soils in Rupandehi district, Nepal.

Table 2. 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; TCE; 7 yr	Silty Clay
No tillage w/o mulch plus mulch	0.22 0.58	Rampur 5 yr	Silt Loam
No tillage ± mulch	ND[2]	Baireni; 2 yr; resampled after 5 yr, analysis pending	Clay loam
Permanent Bed RWM	0.78	Nashipur; 4 yr	Sandy loam
Permanent Bed ± mulch RWMz+M	1.06	Nashipur; 4.67 yr	Sandy loam
B. Organic Inputs (CT)[3]			
Straw return 8 Mg/ha/yr	0.21	Bhairahawa; Crop residue; 7 yr	Silty Clay
Straw return 10 Mg/ha/yr	0.16	Parwanipur LTFE; 23 yr	Silt Loam
Manure 20-30 Mg/ha/yr	0.37-0.62	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	
D. Fertilization[4]	0.01-0.15	3 LTFE's; 23-25 yr	

[1] All locations are in the terai of Nepal except for the permanent beds which are in NW Bangladesh. Long-term fertility experiments (LTFE's) are located at NARC Research Centers at Bhairahawa, Parwanipur and Tarahara
[2] ND = not detectable
[3] CT = Conventional tillage; organic inputs are on fresh weight basis; straw was mature and dry. FYM was applied at 10 Mg/ha wet wt/ crop and was estimated to contain 4 Mg/ha dry wt/crop. Double (rice-wheat; 2 sites) and triple (rice, rice, wheat; 1 site) cropping was practiced
[4] Measured relative to unfertilized control

The project's tillage and residue management experiments did not run long enough for us to experimentally measure SOC changes over the time periods needed to reach new C equilibrium levels, so a modeling approach was used to predict changes in SOC stocks over time. The RothC and CENTURY models were first used to model C dynamics for the long-term soil fertility experiments in Nepal, with only a single data point for verification. This exercise was only partially successful. Figure 8 shows that RothC predicted the single data point well, but the projected future increase in SOC seemed unreasonably high, given that SOC content should be close to equilibrium after 25 years of double and triple cropping in this environment. In contrast, CENTURY under-predicted SOC contents but suggested that SOC levels were close to equilibrium. A simple, spread sheet based, 2-pool model was developed at Cornell as an alternative approach. This model provided the data fit of the RothC model and the carbon trajectory of CENTURY.

We included a tillage factor, where no-tillage decreases decomposition rates, in the 2-pool model and used the model to predict the dynamics of SOC accumulation in the SM CRSP tillage and crop residue management experiments. Figure 9 shows that increases of SOC stocks of 11-15 Mg C/ha are predicted for the 0-20 cm soil layer following adoption of no-tillage in an experiment carried out on a farmer field at Baireni, Nepal with a silt+clay content of 81 % and low initial SOC content. Increases in SOC stock over time are also predicted for improved management with conventional tillage and with residue return (as a mulch with no-tillage) for both tillage regimes, but with a larger gain under no-tillage. In a second experiment on a similar soil, simply discontinuing the conventional puddling of rice was predicted to increase SOC stock in the 0-20 cm soil depth by about 4 Mg C/ha at equilibrium.

The Cornell SOC model was applied to a variety of management scenarios for the average soil texture found in Rupandehi district. Table 3 shows that the largest gains in SOC stocks would occur with adoption of no-tillage and that residue addition, either as straw or realistic rates of manure, would have a much smaller effect. Figure 10 shows that the effect of soil texture on predicted gains in SOC stocks in

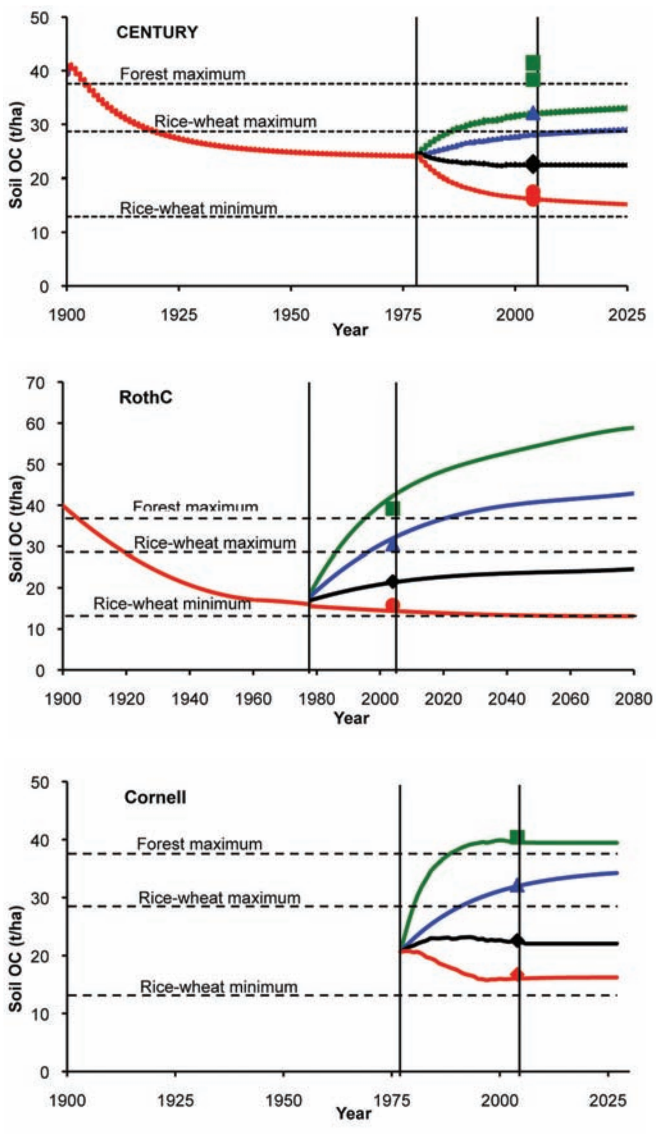


Figure 8. Predictions of CENTURY (upper), RothC (middle), and Cornell (lower) models for SOC stock dynamics in the 0-20 cm soil depth in the Bhairahawa, Nepal long-term soil fertility experiment. Symbols represent measured values and lines the model results. Treatments were farmyard manure (green), grass fallow (blue), NPK (black) and unfertilized control (red). Vertical lines show the experimental period and dashed lines the SOC the maximum or minimum SOC stock values for this site estimated from field surveys of forest and rice-wheat farm sites.

the 0-20 cm depth with adoption of no-tillage varies considerably, with by far the greatest gains occurring in the 80-100 % silt+clay range. This result is consistent with measured effects of soil texture on the difference in SOC stocks between rice-wheat and forest soils (Table 1). Predictions from the model are somewhat higher than this empirical data, suggesting that the tillage factor in the model may need to be adjusted.

How likely is it that farmers will adopt no-tillage in the rice-wheat system? There has been widespread adoption of no-tillage for wheat using drills in NW India and Pakistan, but it took almost 15 years of sustained effort and promotion by CIMMYT and NARES scientists before this happened. The ultimate driving force for adoption was rising labor costs. Unfortunately no-tillage wheat is rotated with conventionally managed (puddled) rice so there are no SOC gains in the cropping system. This project introduced no-till drills to two farmer groups in Nepal (Figure 11), but there was little interest in using them for rice after wheat and farmers were concerned about how to use their manure with no-tillage.

In the 1990s, CIMMYT and NARES scientists introduced surface seeding for wheat (broadcasting seed on untilled soil, or relaying into the rice crop) as a way of promoting timely planting of wheat in heavy textured soils in the Nepal

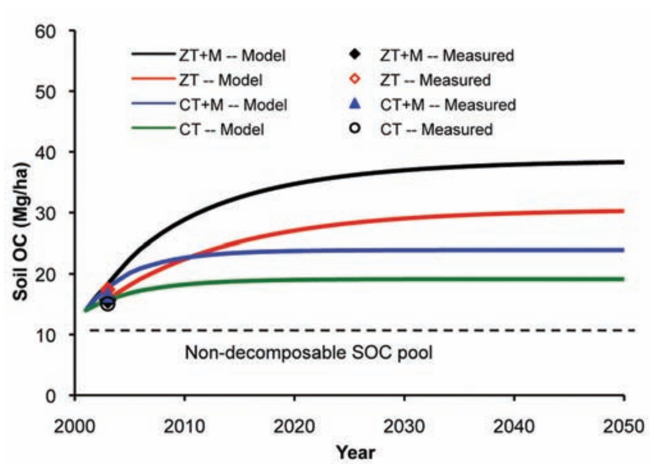


Figure 9. Measured and modeled effects of conventional tillage (CT) and no-tillage (ZT) practices with or without straw mulch (M) on soil organic carbon stock (0-20 cm) for an experiment on a soil with 81% silt + clay at Baireni, Nepal.

Table 3. Modeled effect of management practices on soil C gains for the 0-15 cm soil depth for the average field containing 79 % silt + clay in Rupandehi district, Nepal.

***Management Practice*[1]**	***Soil C Gain 10y (Mg/ha)***	***50y***
Farmer	0.03	0.00
Recommended fertilizer	0.65	0.72
Straw Addition (4 Mg/ha/y)	0.68	0.65
FYM Addition (1 Mg/ha/y)	0.92	1.04
Zero tillage	5.40	8.92
Zero tillage + straw	6.10	9.61
Zero tillage + FYM	**6.82**	**11.34**

[1] A base rate FYM at 1 Mg ha-1 y-1 dry wt is added to all treatments every 5 years
All additions of straw and FYM (above the base rate) were at the same rate

terai. At the time, many farmers were leaving the land fallow after rice due to problems with seedbed preparation for wheat. After an initial push with surface seeding, research programs moved on to working with small equipment and the surface seeding program was discontinued. An extensive SM CRSP survey of farmer use of surface seeding and their experiences found that dis-adoption was high due to farmer uncertainty about how to implement the technology. Nevertheless, some farmers were staunch advocates of the technology and most farmers viewed surface seeding positively. Technical backstopping and support from NARES was the missing ingredient. The SM CRSP explored surface seeding as a way for small, resource poor farmers to adopt no-tillage without equipment. Surface seeding was evaluated for a rice-wheat-mungbean triple cropping system over a five year period in research experiments on light and heavy textured soils. Mean yields of rice and wheat were similar under no-tillage surface seeding (NT-SS) and conventional tillage and seeding (CT) in both soil types. Yields of mungbean were 24-37 percent higher under NT-SS compared to CT on the light textured soil but similar on the heavy textured soil. Mulch had a positive yield effect for all crops, tillage regimes and soils, increasing yields by 10-15 percent for rice, 10-20 percent for wheat and 20-37 percent for mungbean.

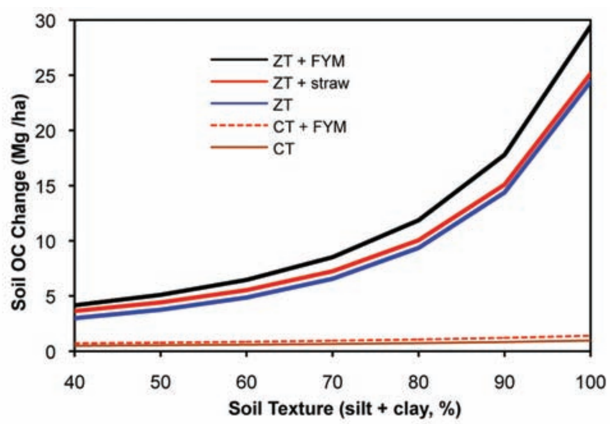


Figure 10. Effect of soil texture, tillage practice (ZT = zero till and CT = conventional tillage with puddling), straw and farmyard manure (FYM) on modeled total gain in SOC stock in a 0-20 cm soil depth cropped to rice and wheat.

The Cornell carbon project developed and promoted the use of permanent raised beds as a resource conservation approach for rice-wheat cropping systems with minimal soil disturbance. Figure 12 shows bed formation using a CIMMYT-NARES developed attachment to the Dong Feng Chinese hand tractor. As noted above, experiments at two sites gave annual increases in SOC stocks of 0.8 to 1.1 Mg C/ha

Figure 11. No-tillage drill introduced to two farmer groups in Nepal. (Photo: J. Duxbury)

*Figure 12. Bed planting attachment to Dong Feng Chinese hand tractor. (*Photo: J. Duxbury*)*

Figure 13. Hybrid rice production on raised beds in Natore district, Bangladesh, showing larger panicles size compared to conventional paddy rice and farmer promoter (Md.Yunus Ali, aka Hanif), farmer (Anil Chandra) and Bangladesh Agricultural Research Institute supporting scientist (Dr. Ilias Hossain).

over a 5 year period. Moreover, farmers were receptive to the raised bed approach (discussed in the Cornell Rice-Wheat Final Report found in this publication) as it increased yield, and reduced water inputs and costs for many crops. The technology spread from an initial 26 farmers to 900 in a four year period using farmer to farmer dissemination of the technology. However, it was hard to get farmers to accept permanent beds for the system as opposed to breaking and remaking beds periodically, especially as tillage is used as a weed control measure. Nevertheless, Figure 13 shows very successful hybrid rice production on permanent beds by a farmer (Anil Chandra) in Natore, Bangladesh. As an early adopter (2003) of permanent beds, he indicated that his yields of wheat and rice had increased from 4-5 to 13-14 and from 8-10 to 16-18 maunds/bigha for wheat and rice, respectively (corresponding to 1.1-1.4 to 3.4-3.6 and 2.2-2.8 to 4.5-5.8 Mg/ha) and production costs were reduced by 30 percent. He also noted an improvement in soil physical condition. Anil used the increased income generated to support his son's education in a MS degree program at Rajshahi University and the development of mobile phone and lumber businesses.

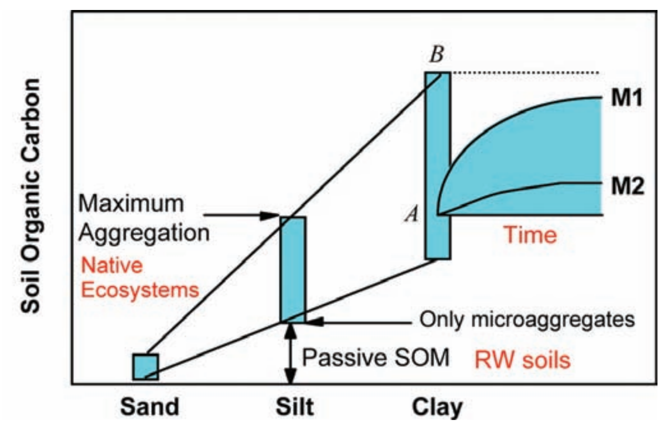
LESSONS LEARNED AND NEXT STEPS

- Measurements of SOC and texture in Nepal databases were unreliable due to methodology problems. A major issue is that most developing country laboratories do not include adequate (most have none) quality control protocols so that there is no way to understand the reliability of analytical data. Simple methods for SOC determination, such as weight loss on heating, still require adequate equipment, reliable power supplies, attention to detail and calibration with "correct data." We found that SOC could be correctly measured but data quality tended to degrade over time. Spectroscopic methods, such as NIR, MIR and hyper-spectral analysis, which offer reliable non-chemical approaches to SOC determination, were not assessed in the current study and we are not aware of this capacity anywhere in South Asia. Future studies should explore use of these methods.

- Farmers in long-term rice-wheat production areas have difficulty relating to scientist's interest in increasing SOC contents or improving soil aggregation because they have little knowledge of soil science and generally no improved soil reference point(s) for comparison. Adoption of reduced or no-tillage practices will likely only occur where the practices bring benefits important to farmers, such as economic gains through reduced costs of production and/or increased productivity. The linkage of SOC sequestration to improved soil performance can then be made and indicators such as a darkening of soil color and softer soils will have practical significance for farmers.

- Global experience with no-tillage has taught us that controlled traffic and surface residue or mulch that control compaction and prevent dispersion and sealing at the soil surface, respectively, are critical components for sustainable no-tillage. These requirements are unfamiliar to rice-wheat farmers and residue return or retention is a challenge due to its many uses, e.g., animal feed, construction, fuel etc. Furthermore, soil properties and constraints evolve over time following a change to no-tillage and new constraints or issues will arise. Consequently, continuing involvement of research and extension communities will be needed to provide solutions and advice as farmer adoption of no-tillage increases.

- The raised bed and furrow system, which we found to be the most effective practice for SOC sequestration represents the largest change for rice culture. While farmers were used to growing vegetables on beds, they were resistant to the permanent bed concept. The inability to use tillage for weed control program was a major reason. Farmers were reluctant to use straw mulch to suppress weeds, even though research had also shown yield and nitrogen benefits to using mulch. Farmers were attracted to machine seeding of wheat on beds but still preferred to transplant rice. Evaluation of direct seeding of rice under farmer conditions will need additional research. Difficulties with beds can arise before aggregate formation develops sufficiently to improve soil physical condition. Dispersion of soil and "melting" of beds can occur with heavy rainfall on silt soils and clods can be generated during reshaping of beds on clay soils. Nevertheless, the water and nitrogen savings, higher yields, reduced production costs and higher economic returns that can be achieved with permanent beds are powerful reasons for following this approach as a resource conserving technology of the future for rice-wheat cropping systems of South Asia.



PARTICIPATING AND COLLABORATING SCIENTISTS & INSTITUTIONS/ORGANIZATIONS

National Agricultural Research Systems (NARS)

Bangladesh

Bangladesh Agricultural Research Institute (BARI)
M.E. Baksh
M. Bodruzzaman
M.I. Hossain
A.M.H.S. Talukdhar

Bangladesh Rice Research Institute (BRRI)
N.I. Bhuiyan
D.N.S. Paul

Nepal

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

Nepal Agricultural Research Council (NARC)
G.S. Giri
S.M. Maskey
R. Munankarmy
S.P. Pandey
D.S. Pathick
S. Rai
G. Sah
K. Sah
R.P. Sapkota
K. Scherchand
J. Tripathi
J. Tuladhar

United Kingdom

Rothamsted Exp. Station
J. Gaunt

United States

Cornell University
C. Adhikari (Nepal Ag. Res. Council--NARC)
S. De Gloria
J. Duxbury
M. Easter (Natl. Res. Ecol. Lab, Cornell Univ.)
J. Lauren
C.A. Meisner (CIMMYT & Cornell On-Site Coordinator-Bangladesh)
G. Panaullal (Bangladesh)
S. Riha
Z. Ross
S. Williams (Natl. Research Ecol. Lab)
P. Woodbury

International Agricultural Research Centers (IARC)

International Maize and Wheat Improvement Center (CIMMYT)

R.K. Gupta (RWC Coordinator)
P. Hobbs (Nepal)
S. Justice (Nepal)
G. Ortiz-Ferrera (Nepal
K. Sayre (Mexico)

International Rice Research Institute (IRRI)

J.K. Ladha

DEGREE PROGRAMS

Degree Programs

Year	Name	Degree	Gender	Institution	Home Country
2003	Gopal D. Bhatta	MSc	M	Inst. Agric. Animal Sci	Nepal
2003	Janma Jaya Gairhe	MSc	M	Inst. Agric. Animal Sci	Nepal
2003	Andrew McDonald	PhD	M	Cornell University	USA

Year	Name	Degree	Gender	Institution	Home Country
2004	Sarad Adhikari	MSc	M	Inst. Agric. Animal Sci	Nepal
2004	Dev B. Gurung	MSc	M	Inst. Agric. Animal Sci.	Nepal
2006	Jagat Adhikari	MSc	M	Inst. Agric. Animal Sci.	Nepal
2006	Subash Adhikari	MSc	M	Inst. Agric. Animal Sci.	Nepal
2006	Rajan Ghimire	MSc	M	Inst. Agric. Animal Sci.	Nepal
2006	Arati Nepal	MSc	F	Inst. Agric. Animal Sci.	Nepal
2006	Mahendra Aryal	MSc	M	Inst. Agric. Animal Sci.	Nepal
2007	Rajendra Gautam	MSc	M	Inst. Agric. Animal Sci.	Nepal
2007	Deepak Sapkota	MSc	M	Inst. Agric. Animal Sci.	Nepal
2007	Puspa Poudel	MSc	M	Inst. Agric. Animal Sci.	Nepal
2007	Shyam Kandel	MSc	M	Inst. Agric. Animal Sci.	Nepal
2007	Nabin Dangel	MSc	M	Inst. Agric. Animal Sci.	Nepal
2008	Sanjay K. Gami	PhD	M	Cornell University	Nepal

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Chapter Eight

Biotechnology

ASSESSING THE EFFECTS OF BT CROPS AND INSECTICIDES ON ARBUSCULAR MYCORRHIZAL FUNGI AND PLANT RESIDUE CARBON TURNOVER AND FATE IN SOIL

MEDHA DEVARE, DEPARTMENT OF CROP AND SOIL SCIENCES
CORNELL UNIVERSITY, ITHACA, NY, USA

JANICE THIES, DEPARTMENT OF CROP AND SOIL SCIENCES
CORNELL UNIVERSITY, ITHACA, NY, USA

JOHN M. DUXBURY, DEPARTMENT OF CROP AND SOIL SCIENCES
CORNELL UNIVERSITY, ITHACA, NY, USA

CORNELL UNIVERSITY

Amount of ^{13}C (g/plant) incorporated into cobs, husks, leaves, stalks, and roots of Cry 3Bb Bt and Non-Bt corn at the V7 and R5 growth stages in a greenhouse experiment in New York.

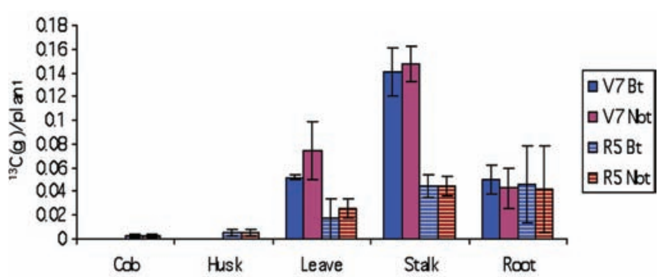
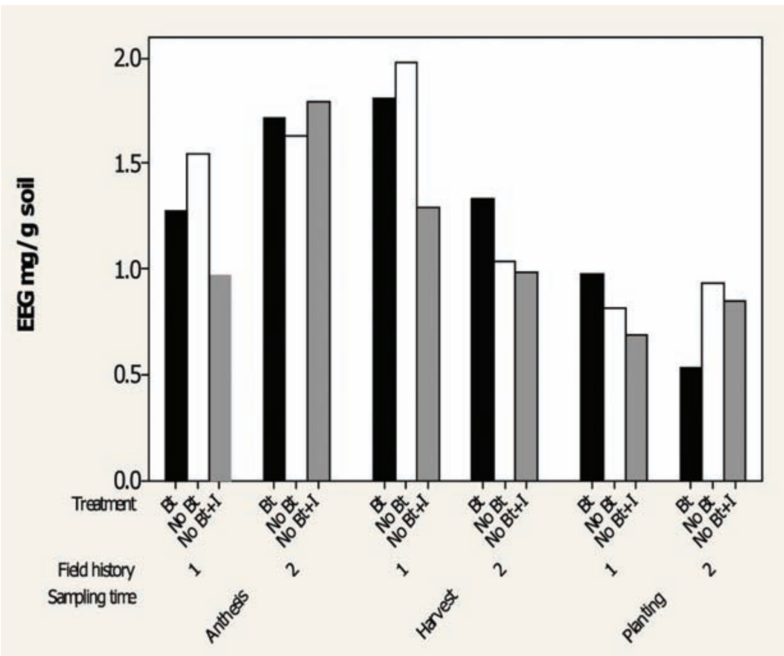


Table of Contents



OVERVIEW & EXECUTIVE SUMMARY

Insect-resistant Bt crops have the potential to increase productivity and decrease the environmental and human health hazards posed by the insecticides normally used to contain pest damage. However, public concerns about the use of this technology abound, among the foremost of which are the potential adverse affects of Bt crops on non-target organisms. Much of the scientific literature in this area has focused on non-target arthropods, with far fewer assessments made to determine if this technology poses any risks to the biomass and diversity of microorganisms in the soil. Further, there is no clear understanding of the dynamics of carbon (C) allocation in these transgenic crops and how any changes may affect in-field rates of residue decomposition, and whether any changes in C turnover might have implications for C sequestration in soil.

This multi-stakeholder, multi-institutional project was developed to determine the effect of Bt corn, cotton, and rice on arbuscular mycorrhizae fungi (AMF) and residue decomposition under field conditions over four consecutive years (2004-2007) in New York (corn) and China (rice) and two consecutive years (2004-2005) in Colombia (cotton).

Corn. Field plots in New York were planted with transgenic Cry3Bb "YieldGard" Bt corn resistant to the corn rootworm (CRW) and the non-Bt corn isoline with and without a pre-emergent treatment of the insecticide tefluthrin applied to control the rootworm. Three replicate plots were established in a field with low rootworm pressure (no recent history of corn cropping); and three replicates of each treatment were established in fields with high rootworm populations (prior history of corn cropping).

Rice. Cry1Ab Bt rice (KMD1) and two non-Bt varieties (Xiushui 11 and and Jiazao 935) were transplanted into field plots in China, and half of each plot was treated with the insecticide triazophos to protect against stem borers.

Cotton. Cry1Ac Bt (Bollgard® technology; variety NuCont 33B) and non-Bt cotton (variety DP 5415) were planted in field plots in Colombia with three insecticide application regimes as follow: (a) use of insecticides to control non-target pests (i.e., non-lepidopteran pests), (b) application of conventional insecticides as normally applied in the region, and (c) application of pesticides that contain Bt as normally applied in the region.

Project activities in Colombia ended in 2006, when Dr. Barrios and his team departed from CIAT, our collaborating institution.

The emphasis of all our studies was on symbiotic associations between plant roots and AMF, soil arthropods important in the primary decomposition of crop residues. The rates of decomposition and fate of Bt vs. non-Bt residues were measured to assess the potential for increasing C sequestration in soil using Bt crops. The crops were chosen so that we could evaluate effects on soil organisms under both aerobic and anaerobic conditions (Bt corn and cotton are grown in aerobic soil, while Bt rice is grown under primarily anaerobic soil conditions) and across three different transformation events, with three different Cry proteins.

Objectives for this project were:

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

PROJECT ACCOMPLISHMENTS

Our findings indicate that there are essentially no differences between Bt and non-Bt corn, cotton, and rice in terms of their effects on AM Fungi (AMF) abundance and diversity, the community structure of bacteria and fungi colonizing residues, and rate of residue decomposition. Carbon allocation to plant parts was only determined for Bt and non-Bt corn, and did not differ.

1. The effect of Bt corn, cotton, and rice on the abundance of AMF was assessed and compared with the non-Bt isolines grown with and without insecticide in field trials. AMF abundance was determined by microscopically enumerating spores, measuring the fraction of roots sampled that contained fungal hyphae, vesicles, or arbuscules, and estimating glomalin, a purported biochemical surrogate for AMF abundance, in corn and rice trial plots.

- Although an effect of growth stage and growing season was often observed, genotype did not affect the abundance and diversity of AMF in corn, cotton or rice.

2. The effect of Bt corn on the diversity of AMF was determined by cloning and sequencing DNA from soil in corn plots and corn roots.
- AMF genera did not differ with corn genotype.

3. Community structure of bacteria and fungi colonizing the field litterbag residues of Bt corn were determined using DNA amplified with fluorescently labeled primers to the 16S rRNA genes and the internal transcribed spacer (ITS), respectively. PCR products were digested in separate reactions using the restriction enzymes HhaI and Sau96I for bacteria and HhaI and MspI for fungi. Terminal restriction fragments were sized, and the resulting data analyzed by use of multivariate statistical approaches. A similar analysis was performed using rice rhizosphere soil since rice residue remaining when litterbags were sampled was insufficient for DNA extraction. Work is still underway to assess the community structure of bacteria in soil from Bt and non-Bt cotton plots.
- There were no differences in the bacterial or fungal communities colonizing transgenic and non-transgenic corn residue and rice rhizosphere soil. However, detectable differences in bacterial and fungal communities colonizing corn residues and rice rhizospheres were observed at different sampling times and growing seasons.

4. Carbon allocation in Bt and non-Bt corn with and without rootworm pest pressure was assessed in the greenhouse using a $^{13}CO_2$ pulse-labeling method. Lignin content of the transgenic and non-transgenic corn plant parts was measured by the acid detergent lignin method.
- Corn genotype had no significant effects on the amount of ^{13}C allocated to plant parts at any phonological stage.
- Although non-Bt corn heights and dry weights were higher than those of Bt corn, only the heights were significantly different.
- Rootworm pressure caused both Bt and non-Bt corn to grow taller than treatments without rootworm pressure.
- Lignin content of the Bt and non-Bt corn was the same. Corn parts had significantly different lignin content, with roots having the most lignin, and leaves and husks the least.

5. Residue decomposition rates were assessed for Bt and non-Bt corn, cotton, and rice in litterbags placed at the soil surface or 10cm below the surface in field plots. It was determined that although the plant parts placed in the litterbags differed in their lignin content, the transgenic and non-transgenic genotypes did not.
- Plant decomposition rates were similar for transgenic and non-transgenic varieties of all three crops.
- Corn and cotton residue placed at the soil surface decomposed slower than that placed at depth, but this difference was not observed for rice residues at the surface, which were under water much of the year.
- Corn and cotton stalks and leaves decomposed faster than the corresponding cob and root samples, respectively.

HIGHLIGHTS OF ACCOMPLISHMENTS

Effect of Bt and Non-Bt Corn, Cotton and Rice Grown With and Without Insecticides on the Abundance and Diversity of AMF

Soils from corn, cotton, and rice field plots established in New York, China, and Colombia in 2004 were sampled at least three times over the annual growing season for each crop to assess the extent of symbiosis with arbuscular mycorrhizal fungi (AMF). AMF abundance was microscopically evaluated by counting spores extracted by wet sieving and sucrose centrifugation from soils sampled from corn and rice plots. AMF hyphal abundance in soil from cotton

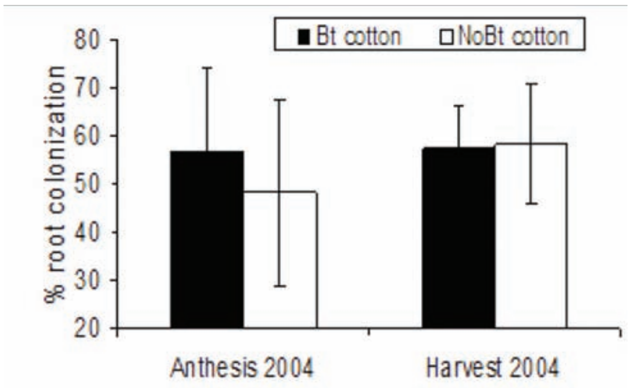


Figure 1. Percent of cotton root length colonized at anthesis and harvest for Cry1Ac Bt and NoBt cotton in 2004 in Colombia. Error bars represent the standard error of the mean.

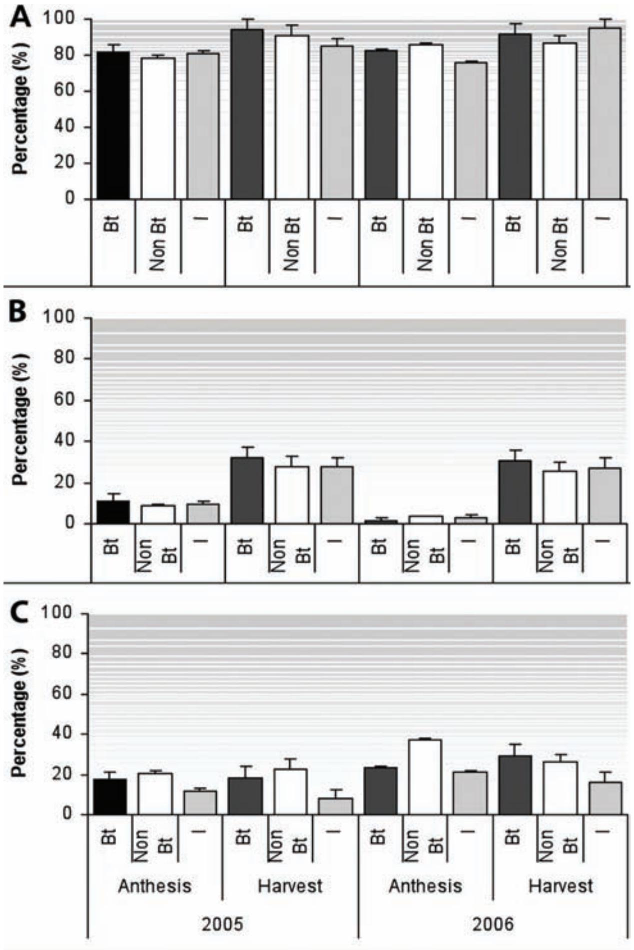


Figure 2. Percent of corn root length colonized by: (A) AMF hyphae, (B) vesicles, and (C) and arbuscules in Cry3Bb Bt, non-Bt, and non-Bt+I corn at anthesis and harvest in 2005 and 2006 in New York. Error bars represent standard error of the mean.

plots was determined using the gridline-intersect method after staining hyphae with Trypan blue. A protocol to estimate abundance of AMF by extracting and measuring glomalin ("easily extractable glomalin," EEG) using the Bradford total protein assay was tested and applied to all 2005 soil samples from the corn and rice trials. AMF infectivity was assessed by measuring the extent of root colonization by hyphae, arbuscules, and vesicles using the gridline-intersect method after staining roots with Trypan blue.

- Colonization of Bt vs. non-Bt corn roots by AMF hyphae, vesicles, and arbuscules did not differ, although effects of crop growth stage and growing season were evident. Hyphal colonization was measured in Bt and non-Bt cotton roots in 2004, and was similar at anthesis and harvest (Figure 1). Colonization of corn roots differed significantly between sampling times within each year ($p<0.0001$; Figure 2A). AMF vesicle colonization differed significantly within ($p<0.0001$) and between years ($p<0.002$), but not between genotype treatments or field histories (Figure 2B). Arbuscule colonization differed significantly between years ($p<0.0003$) but not within years. Arbuscule colonization also differed between treatments ($p=0.0005$), with a significantly lower percent of roots containing arbuscules in the non-Bt+I treatment as compared to the Bt and non-Bt treatments (Figure 2C).
- AMF spore density was significantly affected by plant growth stage in corn bulk soil, and by growing season in corn bulk soil and cotton rhizosphere soil (Figures 3 and 4). Bulk soil was defined as the soil that easily fell off the roots of sampled plants upon shaking vigorously, while rhizosphere soil adhered to plant roots and was collected by squeezing the roots with a gloved hand for rice, and by hitting plant roots against the inside of a collection bucket for corn and cotton. As expected in a paddy system, rice root colonization by AMF was low or nonexistent, and the transgenic Cry1AB Bt rice had no effect (Figure 5).
- Easily extractable glomalin varied by sampling time in both corn and rice (Figures 6 and 7). The only corn treatment effect on glomalin occurred at harvest, when more glomalin was extracted from Bt compared to nNon-Bt and nNon-Bt+Insecticide in plots with a field history of corn cropping, suggesting that more AMF were present in the Bt plots. There was also a significant effect of sampling time ($p < 0.0001$).

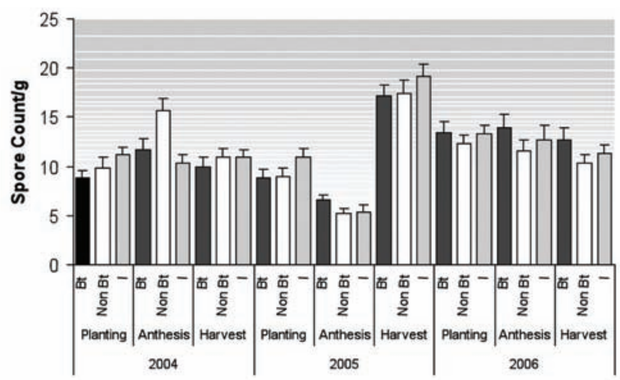


Figure 3. Number of AMF spores/g soil in corn plots at planting, anthesis, and harvest in Cry3Bb Bt, non-Bt, and non-Bt+I corn in 2004, 2005, and 2006 in New York. Error bars represent standard error of the mean.

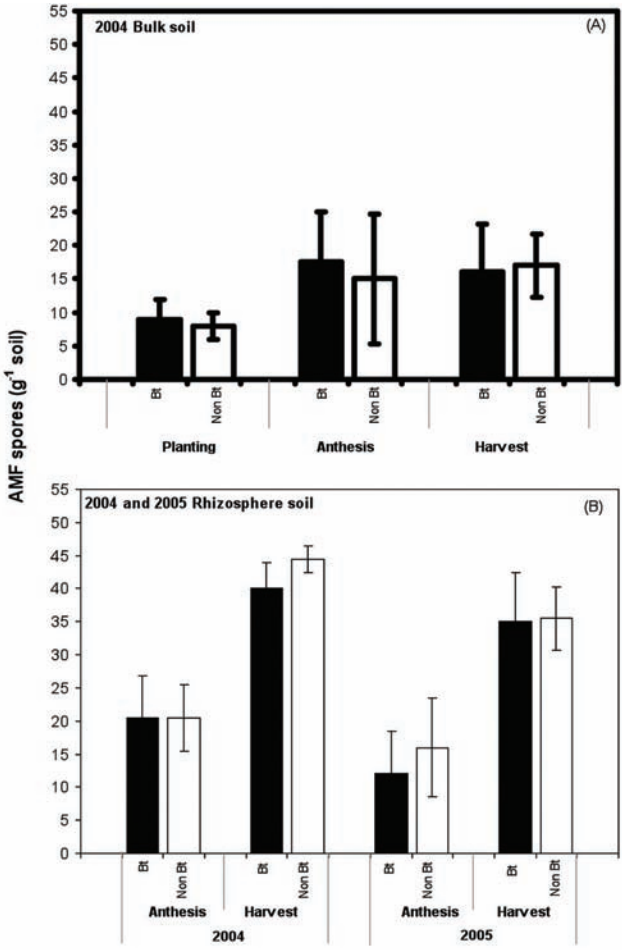


Figure 4. Number of AMF spores/g of (A) bulk soil and (B) rhizosphere soil at planting, anthesis, and harvest in Cry3Bb Bt and non-Bt cotton plots in Colombia in 2004 and 2005. Error bars represent standard error of the mean.

- AMF diversity assessed by cloning and sequencing of DNA from soils and roots in trial plots of corn yielded sequences mostly confined to the genera Glomus and Paraglomus in the division Glomeromycota. AMF genera did not differ with corn genotype (Figure 8).

Effect of Bt and Non-Bt Corn on the Community Structure of Bacteria and Fungi Colonizing Field Litterbag Residues of Bt and Non-Bt Rice

Terminal Restriction Fragment Length Polymorphism (T-RFLP) DNA fingerprinting analysis was employed to assess the community structure of bacteria and fungi on corn

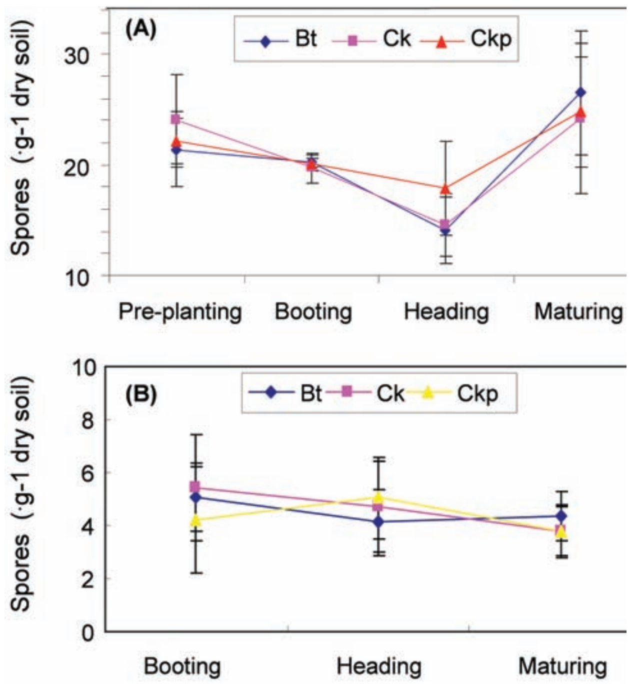


Figure 5. Number of AMF spores in Cry1Ab Bt, non-Bt (Ck), and non-Bt+insecticide (Ckp) rice rhizospheres in (A) 2005 and (B) 2006 in China.

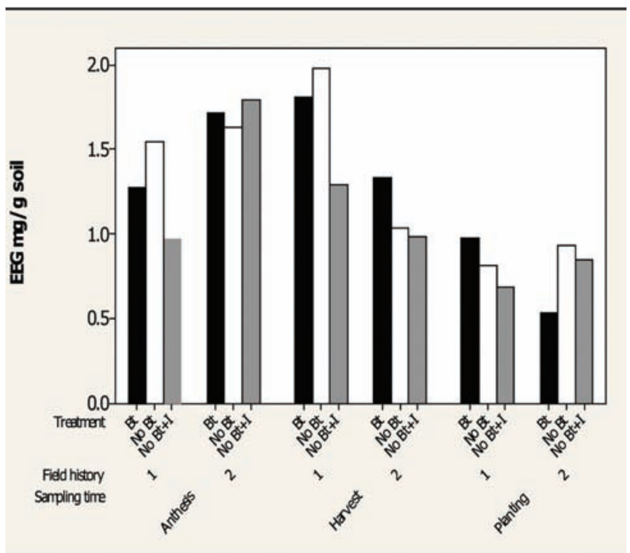


Figure 6. Easily extractable glomalin (mg/g) in bulk soil from Cry3Bb Bt, non-Bt, and non-Bt+I corn plots at planting, anthesis, and harvest in 2005 in New York.

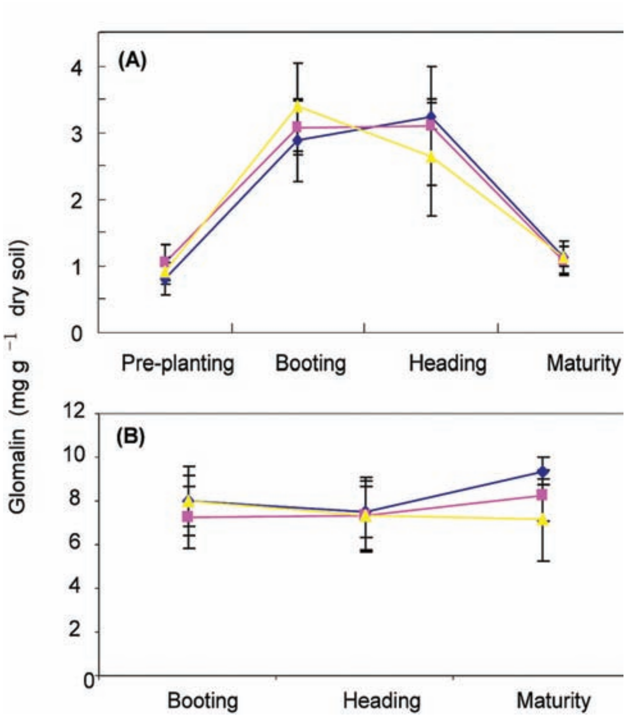


Figure 7. Easily extractable glomalin (mg/g) in soil from Cry1Ab Bt, non-Bt (Ck), and non-Bt+I (Ckp) rice soil in (A) 2005 and (B) 2006 in China.

cobs, roots, and stalks in litterbags placed on the soil surface or at 10 cm depth in field plots. The litterbags were collected at harvest in 2005 and 2006, bacterial and fungal DNA was extracted from residues, amplified, and digested using the restriction enzymes Hha1 and Sau96I for bacteria and Hha1 and Msp1 for fungi. Terminal restriction fragments (TRFs) were sized on an ABI 3730 sequencer, and resulting data analyzed by multivariate statistical approaches. A similar analysis was performed on DNA extracted from rice rhizospheres.

- There were no differences in either bacterial or fungal communities colonizing residues from Bt, non-Bt, or non-Bt+I corn (Figures 9 and 10). However, communities separated very clearly between the two growing seasons, and also showed some separation based on whether residues had been placed at the soil surface or at depth.
- Bacterial and fungal communities did not differ in the rhizospheres of transgenic rice and non-transgenic rice with and without insecticide, although the communities did reveal distinct temporal patterns related to rice development stages (Figure 11).

Greenhouse Assessment of Carbon Allocation in Bt and Non-Bt Corn With and Without Pest Pressure

Allocation of carbon to different corn parts was evaluated in the greenhouse to determine if carbon allocation to roots and shoots differed with varying pest pressure in Bt and non-Bt corn. Bt and non-Bt corn was grown in 2-gallon pots in the greenhouse, and 13C pulse-labeled in saran bag chambers fitted with sampling septa at the V6 stage of plant growth. Western corn rootworm eggs (Diabrotica virgifera virgifera) were injected below the soil surface into the pest pressure treatments, and the amount of ^{13}C in different plant parts measured at phonological phenological stages V7 (knee-high), R5 (reproductive stage 5; nearly all kernels dented), and R7 (harvest maturity).

- Although carbon allocated to corn leaves and stalks was significantly higher than carbon allocated to roots at the V7 stage, there were no differences in C allocated between the Bt and non-Bt corn when assessed at the V7 and R5 growth stages (Figure 12).
- Non-Bt corn grew taller than Bt corn, although there was no difference in dry weights (Figure 13). Rootworm pressure had an effect on both genotypes, causing an increase in plant height compared to control plants without rootworms.
- Lignin content as measured by the acid detergent method did not vary with corn genotype, although lignin content in the plant parts was significantly different as follows: root lignin > cob > stalk > leaf > husk lignin (Figure 14).

Comparison of Residue Decomposition Rate for Bt vs. Non-Bt Genotypes of Corn, Cotton and Rice in the Field

Decomposition rates were assessed by the ash-free weight loss method for residue in litterbags placed on the soil surface or at 10cm depth in field plots for 14, 62, and 100 weeks (corn cobs and stalks and leaves), 2, 4, 8, 12, 26, and 39 weeks (cotton roots and stalks and leaves) and 52 and 88 weeks (rice straw and roots).

- There were no differences in residue decomposition rates for transgenic and non-transgenic genotypes of all three crops, but corn and cotton residue placed at the soil surface decomposed slower than that placed at depth (Figure 15). This difference was not observed for rice residues at the surface, which were under water much of

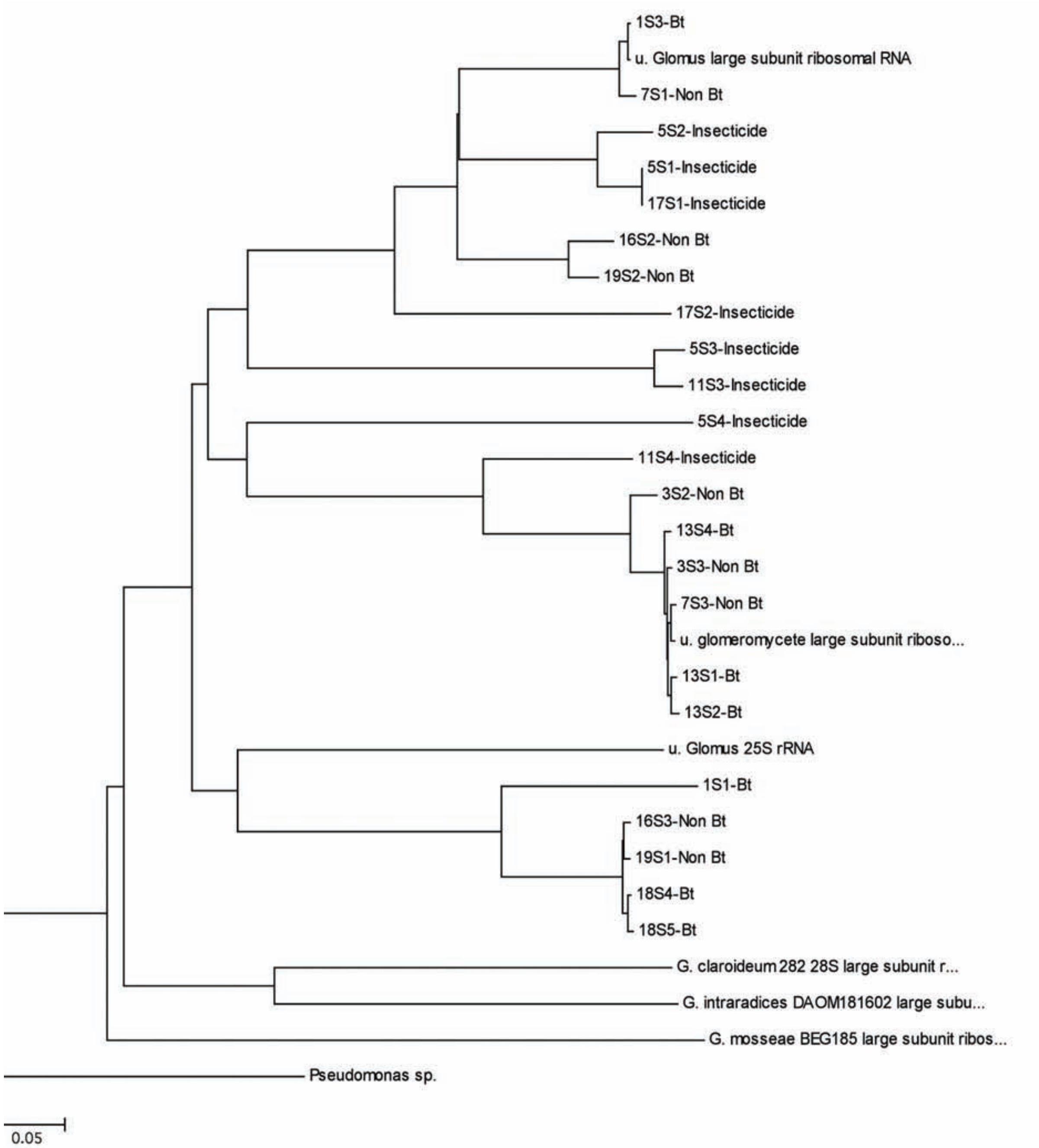


Figure 8. Neighbor-joining phylogenetic analysis of large subunit rRNA gene sequences obtained from AMF inhabiting the rhizosphere soil of Cry3Bb Bt, non-Bt, and non-Bt with insecticide corn at anthesis in 2005 in New York.

the year, and therefore subject to largely anaerobic conditions. Corn and cotton stalks and leaves decomposed faster than the corresponding cob and root samples, respectively.

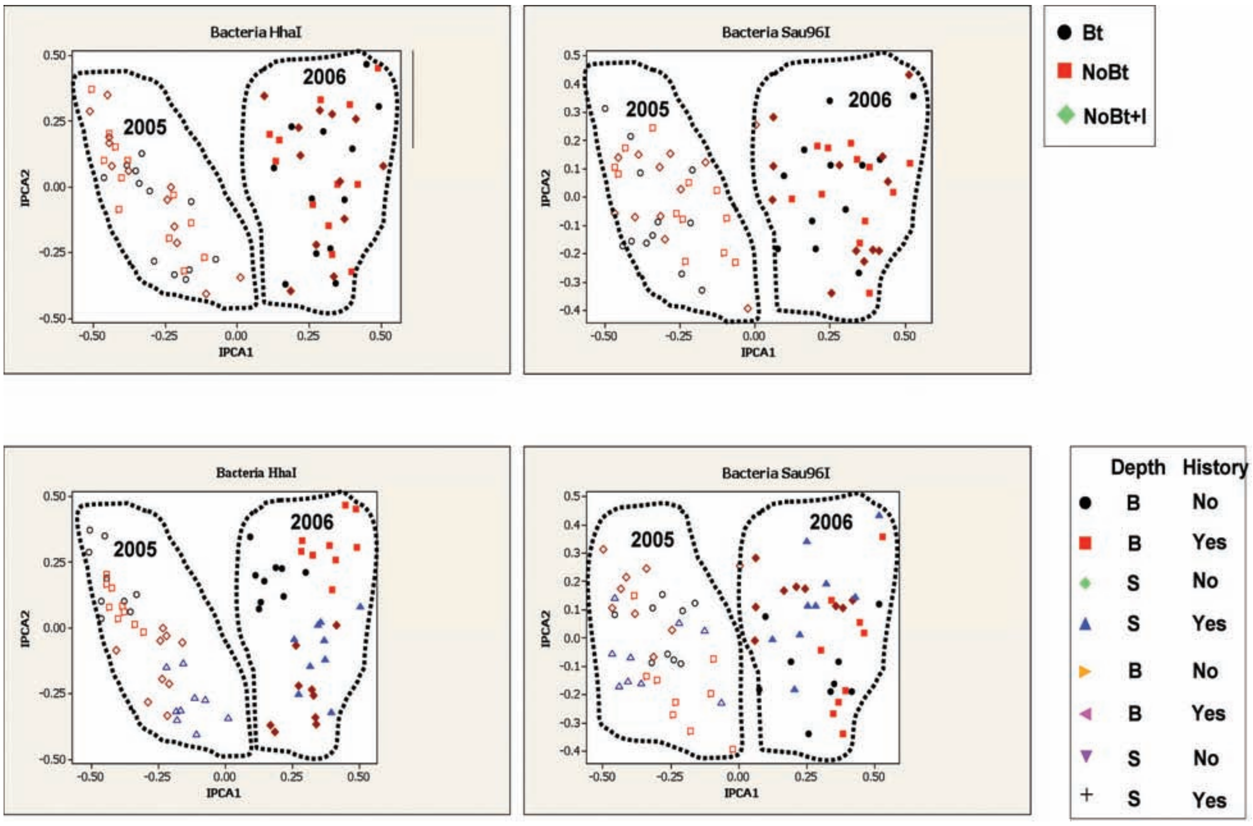


Figure 9. Molecular analysis of bacterial community composition on the surfaces of corn residues from Cry3Bb Bt, non-Bt, and non-Bt+I plots in New York in 2005 and 2006. Main effects with Multiplicative Interactions (AMMI) analysis of the bacterial community terminal restriction fragment length polymorphisms (T-RFLP) after digestion of bacterial PCR products with HhaI and Sau96I. Top: samples do not separate by treatments; bottom: samples separate by year and placement. B=buried at 10cm; S=soil surface; yes=with corn cropping history; no=without corn cropping history.

LESSONS LEARNED AND NEXT STEPS

Results from these studies were expected to establish whether Bt corn, rice, and cotton have any effect on arbuscular mycorrhizal fungi or residue decomposition rates under field conditions—both critical pieces of information for the agencies and processes governing the regulation of Bt crops. Transgenic corn and cotton are widely grown, and there is every indication that Bt rice is also likely to be enthusiastically adopted, particularly in developing countries. No demonstrable effects of the transgenic Bt isolines were observed on AMF or residue decomposition in the field for any of the three crops studied. Further, Neither Bt corn or Bt rice had any effect on bacterial or fungal communities in the field, although temporal and spatial effects were generally observed, suggesting that our experimental methods did work under the circumstances of these studies. There were no differences in plant growth, carbon allocation to roots and shoots, and lignin content between Bt and non-Bt corn in the greenhouse. Based on our results with these three different crops grown in very different environments, it is therefore unlikely that transgenic Bt corn, rice, and cotton will have deleterious consequences on cropping systems and nutrient dynamics through effects on bacterial or fungal communities—both symbiotic and non-symbiotic—or by affecting residue decomposition rates.

Our data add to a substantial body of information indicating no observable short-term effects on soil microbial commu-

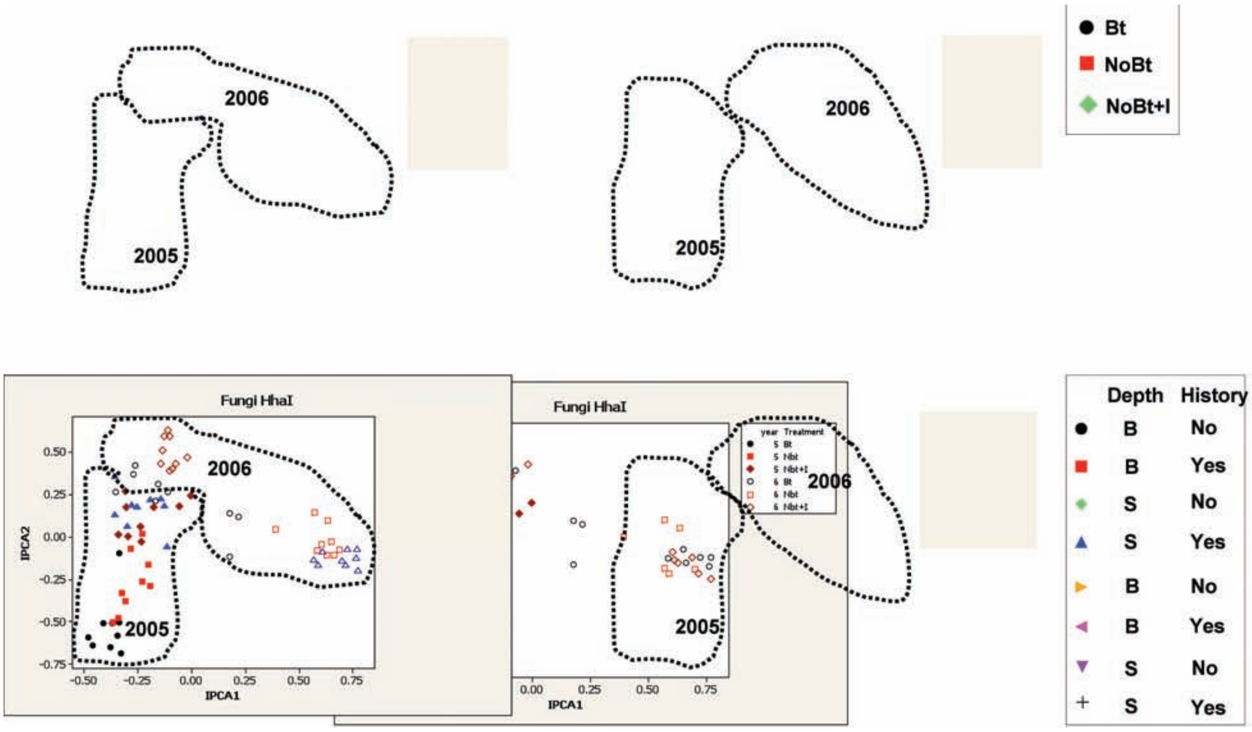


Figure 10. Molecular analysis of fungal community composition on the surfaces of corn residues from Cry3Bb Bt, non-Bt, and non-Bt+I plots in New York in 2005 and 2006. Main effects with Multiplicative Interactions (AMMI) analysis of the fungal community terminal restriction fragment length polymorphisms (T-RFLP) after digestion of fungal PCR products with HhaI and MspI. Top: samples do not separate by treatments; bottom: samples separate by year and placement. B=buried at 10cm; S=soil surface; yes=with corn cropping history; no=without corn cropping history.

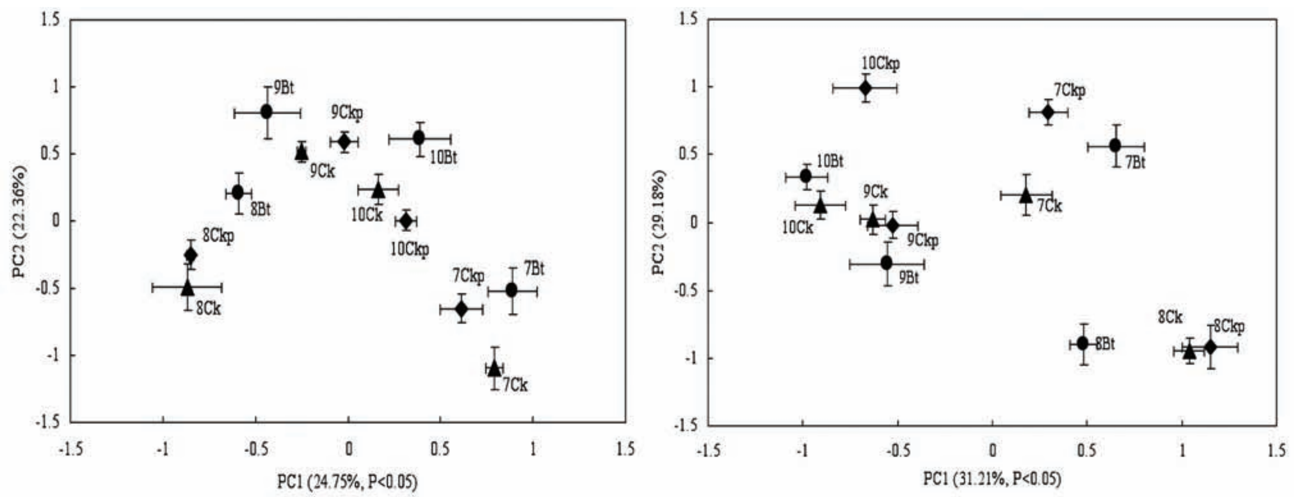


Figure 11. Principal Component Analysis (PCA) of T-RFLP fingerprints of bacterial 16S rRNA gene fragments (left), and fungal ITS region fragments (right) amplified from DNA extracted from the rhizosphere soil of Cry1Ab Bt, Ck and Ckp rice at different stages of development in the field in 2005 in China. 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.

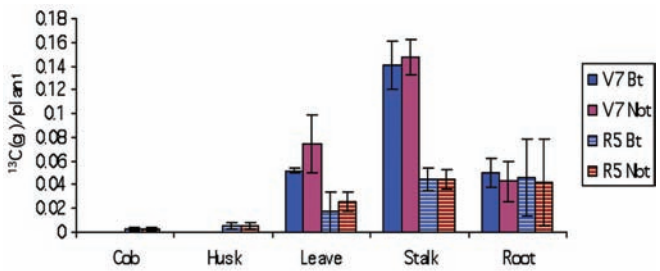


Figure 12. Amount of ^{13}C (g/plant) incorporated into cobs, husks, leaves, stalks, and roots of Cry 3Bb Bt and Non-Bt corn at the V7 and R5 growth stages in a greenhouse experiment in New York.

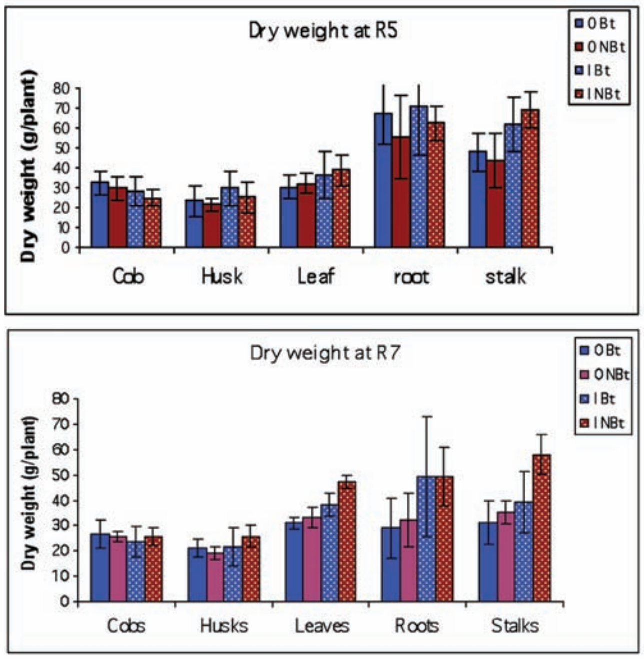


Figure 13. Dry weight (g) of Cry3Bb Bt and non-Bt corn cobs, leaves, husks, roots, and stalks at (A) R5 and (B) R7 growth stages with (I) and without (0) insect pressure (P = 0.05) in a greenhouse experiment in New York.

nities or processes. However, it still remains to be seen if short-term effects (or lack thereof) are accurate indicators of longer term effects on the soil ecosystem. Longer-term field-monitoring, perhaps at a less intensive level than typically undertaken for experimental studies is one direction to take that will build upon our current body of knowledge and make it more robust. Useful though such monitoring would be, there are clear questions regarding what indicators might be appropriate reporters of ecosystem function, and who might actually pay for and do the monitoring.

Another next step pertains to the perception that genetically modified crops significantly reduce pesticide use, with positive repercussions for environmental and human health—the latter being particularly true in developing countries. It is not clear whether pesticide use overall does in fact decrease significantly with the use of GM crops; farmer-field surveys coupled with robust environmental sampling in a variety of locations would go a long way towards definitively answering this question.

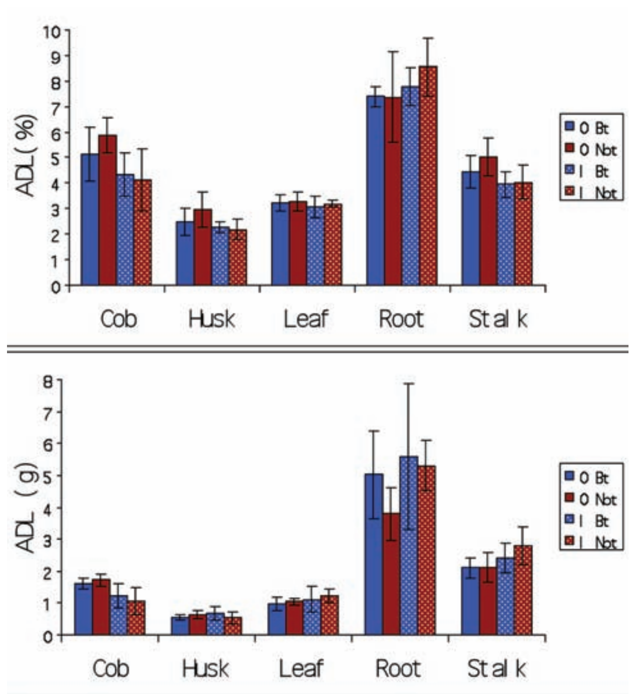
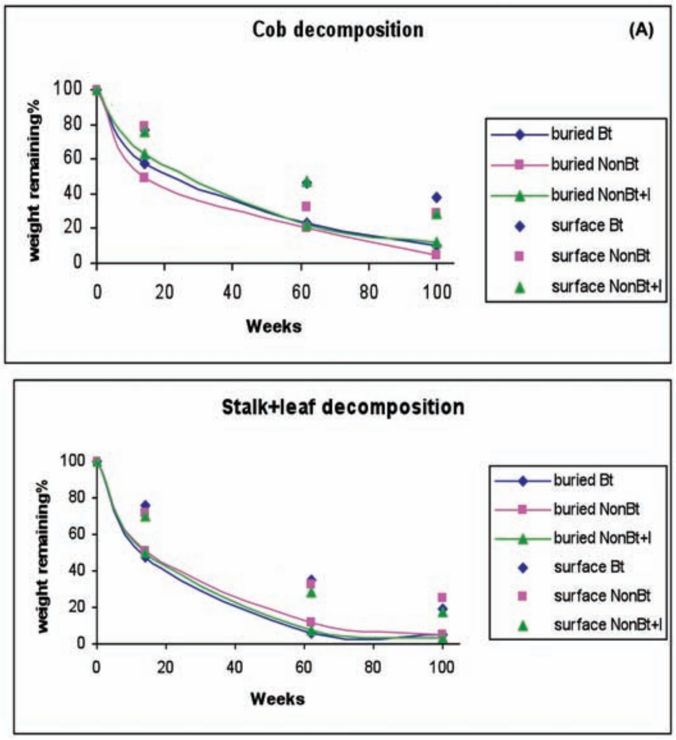
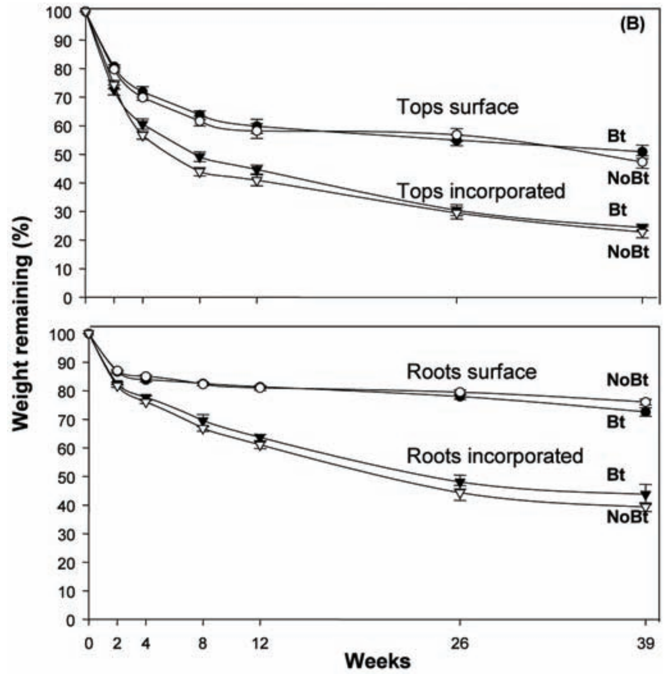


Figure 14. Acid detergent lignin content of Cry3Bb Bt and NonBt corn cobs, husks, leaves, roots, and stalks at R5, with (I) and without (0) insect pressure (P = 0.05) in a greenhouse experiment in New York.





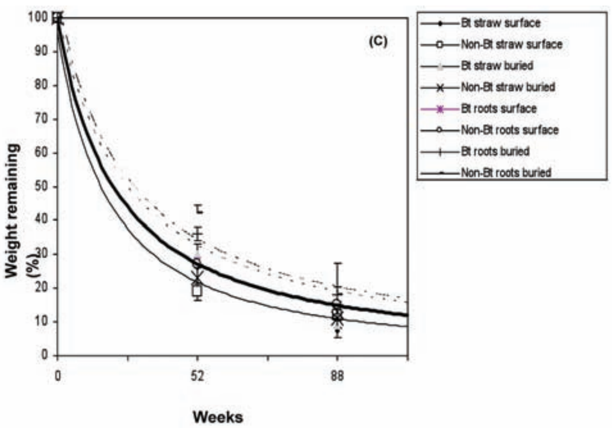


Figure 15. Decomposition of (A) cobs and stalks and leaves of Cry3Bb Bt and non-Bt corn in litterbags placed at the surface or at 10 cm depth in field plots for 14, 62, and 100 weeks in New York; (B) stalks and leaves and roots of Cry1Ac Bt and non-Bt cotton in litterbags at the surface or at 10-15cm depth in field plots for 2, 4, 8, 12, 26, and 39 weeks in Colombia; and (C) stalks and leaves and (B) roots of Cry1Ab Bt and non-Bt rice in litterbags at the surface or at 10 cm depth in field plots for 52, and 88 weeks in China.

PARTICIPATING AND COLLABORATING SCIENTISTS & INSTITUTIONS/ORGANIZATIONS

National Agricultural Research Systems (NARS)

China

Zhejiang University
Weixiang Wu

Colombia

International Center for Tropical Agriculture (CIAT)
Edmundo Barrios

United States

Cornell University
Leslie Allee
Medha Devare
John Duxbury
John Losey
Daniel Peck
Janice Thies

DEGREE PROGRAMS

Degree Programs

Year	Name	Degree	Gender	Institution	Home Country
2006	Luz Marina Londoño	MSc	F	Cornell University	Colombia
2007	Liu Wei	PhD	F	Zhejiang University	China
2008	Hao Hao Lu	MSc	M	Zhejiang University	China
2008	Kai Xue	PhD	M	Cornell University	China

Non-Degree Programs

Name	Home Country	Gender	Dates
Raquel Serohijos	Philippines	F	June 2005-May 2006
Hao Hao Lu	China	M	June 2006-Aug 2006

PUBLICATIONS, PRESENTATIONS AND REPORTS

Journal Series and Books

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.

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

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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.*

Presentations

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Chapter Nine

Biotechnology

GENETIC CHARACTERIZATION OF ADAPTIVE ROOT TRAITS IN THE COMMON BEAN, *PHASEOLUS VULGARIS*

C. EDUARDO VALLEJOS, DEPARTMENT OF HORTICULTURAL SCIENCES
UNIVERSITY OF FLORIDA, GAINESVILLE, FL, USA

JAMES W. JONES, AGRICULTURAL AND BIOLOGICAL ENGINEERING DEPARTMENT
UNIVERSITY OF FLORIDA, GAINESVILLE, FL, USA

MELANIE CORRELL, AGRICULTURAL AND BIOLOGICAL ENGINEERING DEPARTMENT
UNIVERSITY OF FLORIDA, GAINESVILLE, FL, USA

UNIVERSITY OF FLORIDA

Projected images of a young bean seedling. Data was rendered using Maximum Intensity Projection (MIP) and analyzed using pixel intensity thresh-holding using ParaVision XTIP Image Viewer.

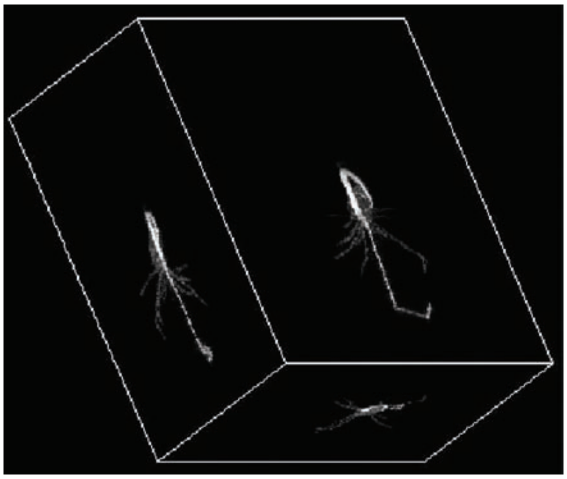
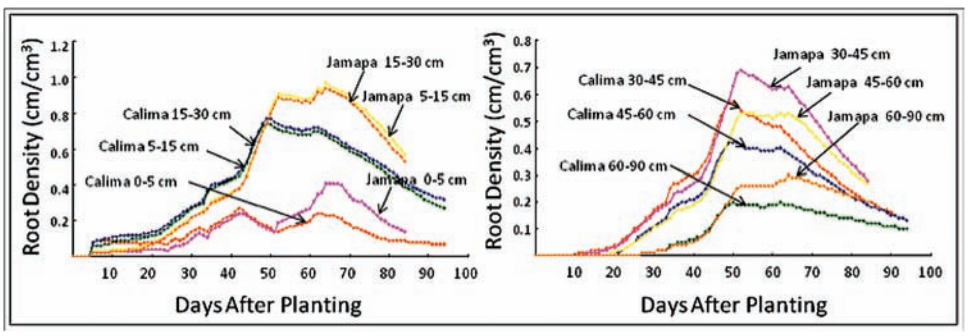


Table of Contents



OVERVIEW & EXECUTIVE SUMMARY

The major focus of the University of Florida biotechnology project was the development of new technologies to characterize root growth and development. The rationale for this approach was based on the proposition that these new methodologies may help identify root traits with adaptive value to marginal soil conditions. For instance, 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 common bean was selected as the model organism for these studies for several reasons. This legume represents a major source of protein and folic acid to over half a billion people in Africa and Latin America. In addition, genetic variation for a large number of traits found in the germ plasm of this species coupled to the genetic resources in the form of a genetic linkage map and several genomic and cDNA libraries could be exploited to generate bean cultivars better adapted to marginal soil conditions.

Root growth and development of young bean seedlings of Andean and Mesoamerican origin have been characterized using 2D and 3D systems. Two-dimensional rhizotrons were used to characterize the responses of bean genotypes to high and low phosphorous levels in the root media. These experiments have uncovered genetic variation for phosphorous-level responses which could be exploited in bean breeding programs. Furthermore, a magnetic resonance imaging (MRI) protocol was developed for obtaining 3D images of intact roots grown in mineral soil. A set of algorithms were also developed to process and quantitatively analyze root images – root growth rates and branching patterns. These traits are important because they can determine the efficiency with which plants can extract water and mineral nutrients from the soil. MRI analysis has also detected significant differences in growth and development among the bean cultivars analyzed. BEANGRO, a computer crop model for the common bean, was used to simulate root growth and development of Andean and Measoamerican genotypes in a sub-tropical environment. The model was used to analyze the effect of irrigation vs. rainfall. This analysis revealed significant differences in root density and root depth. Genetic variation for these traits could be manipulated to produce better adapted cultivars.

A large number of previously mapped molecular markers (PstI genomic clones) have been sequenced. These sequences have been used to identify informative single nucleotide polymorphisms (SNPs) between Andean and Mesoamerican bean genotypes, and develop allele-specific primers. PCR-based markers represent an efficient tool for genomic analysis of traits like root growth rates and branching pattern. These markers can facilitate the genetic analysis of these traits and can also be used as tags for genes controlling those traits. These tags in turn, can be used to follow the transfer of desirable traits into new cultivars.

Objectives for this project were:

1. 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*.
2. Survey *Phaseolus vulgaris* Accesssions from Andean and Mesoamerican Origin, and Assess the Extent of Genetic Variation in Root Morphology, Size and Growth Rate.
3. Identify and Map, via QTL Analysis with Molecular Markeres, Genes that Control Root Characteristics in the Common Bean.
4. Add the Genetic Information to the Existing Crop-Soil Model to Predict the Impact of Using Genetically Improved Cultivars in Specific Soil Environments.

PROJECT ACCOMPLISHMENTS

- Development of MRI protocol to visualize 3D images of intact roots in mineral soil.
- Developed algorithms to process and analyze MRI-derived root image data.
- Developed a 2D system to evaluate root growth.

- Characterized natural genetic variation in root growth and morphology, and in response to soil-phosphorus levels.
- Development of Sequence-Tagged Sites (STS) for the *Phaseolus vulgaris* linkage map

HIGHLIGHTS OF ACCOMPLISHMENTS

Objective 1. 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*

Identification of Root Medium Compatible with MRI Technology

The transparency of soils to both magnetic fields and electromagnetic radiation in the radio frequency range has made it possible to use (MRI) to visualize intact roots in soil. MRI is an application of nuclear magnetic resonance (NMR) spectroscopy, a technique that targets nuclei with an odd number of protons or neutrons. MRI of biological systems most commonly uses the resonance signal of hydrogen nuclei because they have an unpaired proton with a spin, and are the most abundant in living organisms.

The resonance energy emitted by the excited nuclei in the RF range constitutes the signal captured by sensitive receiving coils. The resonance signal contains information on the amplitude, frequency, phase, duration of the resonance, and spatial distribution that is used to construct computerized 3D images. For this purpose, the 3D space is divided in voxels which are volume units representing a value in the 3D grid. The amplitude and duration are affected by the relaxation processes T1 (spin-lattice) and T2 (spin-spin). Selection of the appropriate duration and frequency of RF pulses can lead to the detection of specific spin populations with distinct density, T1 and T2 characteristics.

We have been fortunate that at the University of Florida the Advanced Magnetic Resonance Imaging and Spectroscopy Facility makes its spectrometers available campus wide, and has provided consistent and excellent training to interested plant scientists. We have received guidance and technical assistance from Dr. Stephen Blackband from the UF McKnight Brain Institute.

The first challenge in obtaining root images via MRI technology is distinguishing soil-water from root-water. As mentioned earlier, MRI of biological samples targets protons simply because they have an unpaired proton and the most abundant. This problem was solved by obtaining images based on T2 relaxation signals. Obviously, protons interact with soil particles in a different way than with biomolecules. The second problem was how to deal with the presence of mineral iron soil particles. Iron (Fe) has paramagnetic properties, due to the presence of unpaired electrons, and can cause interference in MRI. However significant interference occurs only when mineral iron is in excess of 2 percent. This problem was solved by screening the following media for compatibility with MRI technology:

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

Scans of the various soil types dispensed into plastic 4-inch pots and containing different water levels up to field capacity were carried out with two different spectrometers. Initial scans were performed on a 3T Siemens Allegra head scanner with a 60 cm bore. Results with this scanner were poor as it provided less than adequate signal to noise ratio (SNR); this was mainly due to low field strength, gradient power limitations, and an inadequate RF coil. Much better images were obtained instead with another spectrometer that has a 4.7T Oxford magnet and greater operational flexibility; the higher power provided the necessary resolution for imaging the roots. This spectrometer has a Bruker Biospin Avance console and ParaVision software.

The best results were obtained with soils belonging to the Kendric series that is classified as a Loamy Siliceous Hyperthermic Arenic Paleudult. Organic debris (dead roots, weed seeds, etc.) were removed by sieving the soil through a USA Standard Testing Sieve No 40 and autoclaving at 15 psi and 120^{o}C for 30 minutes.

Development of an MRI Protocol for Intact Roots Grown in Soil

Based on phantom tests, soils of the Kendric soil series with water content near field capacity was chosen as the medium for plant growth and imaging. Bean seedlings were grown in a plastic pots containing the selected soil. Based on phantom tests carried out with the 1% agarose-filled capillary tubes, seedling were scanned in the spectrometer after shimming and using Spin Echo (SE) scans to localize the pot, and the root images were captured using Rapid Acquisition with Relaxation Enhancement (RARE) phase encoding scans.

Image Processing and Quantitative Analysis of Root Growth

A major obstacle in this project was a methodology to analyze root images quantitatively. Dr. Baba Vemuri from the UF's Computer and Information Science and Engineering Department solved this problem using a tensor model to develop a set of algorithms that can trace the roots in 3-D space (Figure 1). These root traces and images have been processed with a novel de-noising approach (Subakan et al. 2007), and utilized to derive a probability function that describes root volume, root density and branching patterns. A three-stage scheme was followed in which novel algorithms were developed to process MRI data and extract signatures of the root system in 3-D (Subakan et al. 2007). Briefly, the first processing step involved denoising the input MRI data set using a nonlinear coherence enhancing diffusion equation (Figure 2). In the second stage, local orientation information, contained in the given data, was derived with the Gabor steerable filter (Liu et al. 2002). The output of this image processing stage is an orientation map, a discrete set of local orientations at each voxel indicating the orientations along which there is possibly of some useful information. Finally, in the third stage, a continuous mathematical model of the orientations of the voxels was developed along a numerically stable algorithm to estimate the probability surface at the root junction with a maximum that describes the orientation of the branches in the root system. These mathematical models of the root system enabled us to estimate volumetric and branching parameters (See next section). The non-destructive nature of MRI allowed us to obtain root scans over a period of time to study patterns of root growth and development including branching patterns as shown in Figure 3.

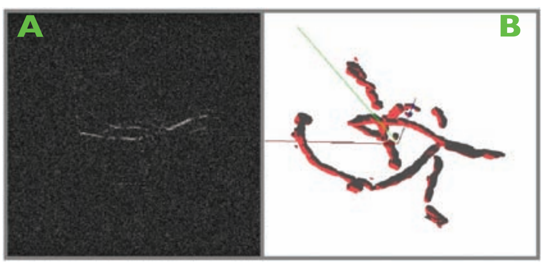


Figure 1. MRI data from an 8-day old seedling. A) Slice #119, B) Digitized trace.

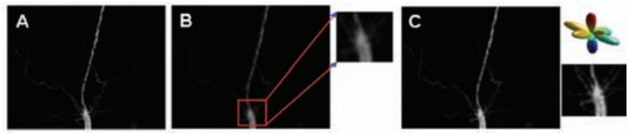


Figure 2. A, View of real MRI data (256 x 256 x 128 pixels. B, Edge enhancing anisotropic diffusion with local scale = 0.5, and 30 iterations. C, our feature-preserving smoothing method in 4 iterations together with a probability map illustrating the bifurcationstructure.

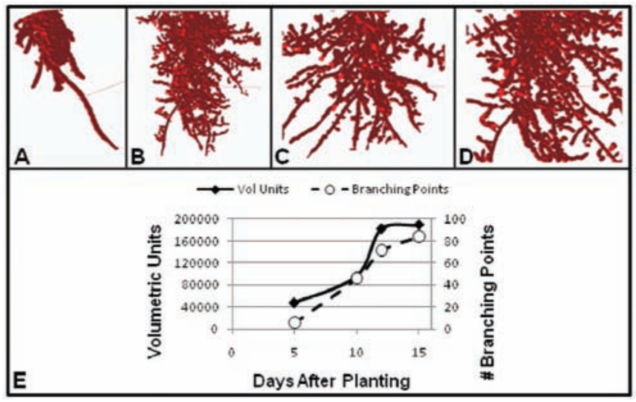


Figure 3. Growth and developmental trajectories. 3D surface map ofthe root of a young seedling grown in sandy soil (A-D). Growth curveusing arbitrary volumetric units and the increase in branching points (E).

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

Evaluation of Genetic Variation for Root Characters

An assessment of genetic variability for root growth and responses to low soil phosphorous levels was carried out with the following accessions: the Andean landrace ‘G19833', the Andean breeding lines ‘Calima’ and the Mesoamerican landrace ‘Jamapa’; the latter two are the parents of a recombinant inbred (RI) family (F10) that can be used for mapping genes controlling root traits. Accession G19833 has been reported by J. Lynch to have root responses that are adaptive to low phosphorous availability.

Three types of 2D rhizotrons were built and evaluated for their suitability for growing young bean seedlings, but more importantly, for the ease with which root growth and development could be followed and measured. The first type of rhizotron encases a layer of soil between black and clear Plexiglas sheets separated by 3 mm spacers placed at the lateral edges. It also has a soil bed attached to the top to accommodate the large bean seed. The rhizotron is tilted back at a slight angle with the clear plexiglas sheet facing down to force the roots to grow against it and facilitate their viewing. Roots were scanned, and the scans were analyzed using Image Pro Plus (MediaCybernetics http://www.medicy.com), a software package commonly used in medical studies (Figure 4). Quantitative analysis of the early stages of root growth with this system has revealed drastic differences between the Mesoamerican and Andean landraces Jamapa and G19833, respectively (Figures 5 A & B). G19833 displayed a more aggressive root growth pattern that appears to facilitate early seedling establishment in the field. For instance, the rate of tap root elongation in G19833 is seven times greater than in Jamapa. This high growth rate is accompanied by a high rate of root branching. The rate of branch addition in G19833 is 10 times greater than in Jamapa.

The second type of rhizotron was built without any soil because poor aeration in the middle appeared to be a limiting factor as roots tended to grow primarily towards the edges. This new rhizotron consisted of two plexiglass sheets that were separated by two thin (25 mm wide X 5 mm thick) gasket strips on both sides of the system. Blue germination paper (Anchor Paper Co., St. Paul, MN) was sandwiched between the gasket and one plexiglass sheet. The components of the system were then clamped together. Seedlings with 1 cm long tap roots were placed at the top between one of the plexiglass sheets and the nutrient-soaked (modified Hoagland solution) germination paper. The rhizotrons were then placed in 10 cm-deep nutrient solution in plastic containers. These were covered with cellophane and black foil to prevent light from reaching the roots and to reduce water evaporation. Using the blue germination paper as a backdrop, the roots can easily be scanned, and the root images can be analyzed to measure the root patterns of tap, basal, and lateral roots, the branching patterns and root angles.

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. Tap, basal and lateral roots from Jamapa elongated at a slower rate with fewer numbers of laterals compared to Calima (Figure 6). Indeed, the tap root from Jamapa was less than half the length of that from Calima after 10 days (Figure 6A). The tap root length, basal root length, and number of laterals seem to slow their elongation rates after 6 days for both Jamapa and Calima. Lateral root growth for both Jamapa and Calima continued in a linear fashion at 14 days after planting (data not shown) suggesting that while the number may not be increasing significantly, the laterals continue to elongate. For both Cal-

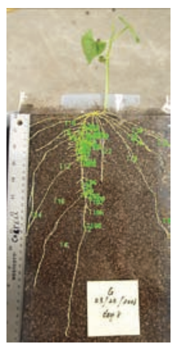


Figure 4. Eight-day old seedling of G19833.

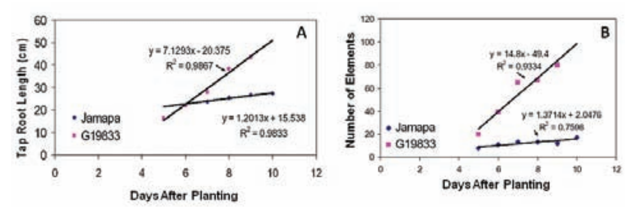


Figure 5. Quantitative analysis of root growth in the landraces Jamapa (Mesoamerican) andG19833 (Andean).A) Rates of tap root growth, B) Rate of lateral root emergence.

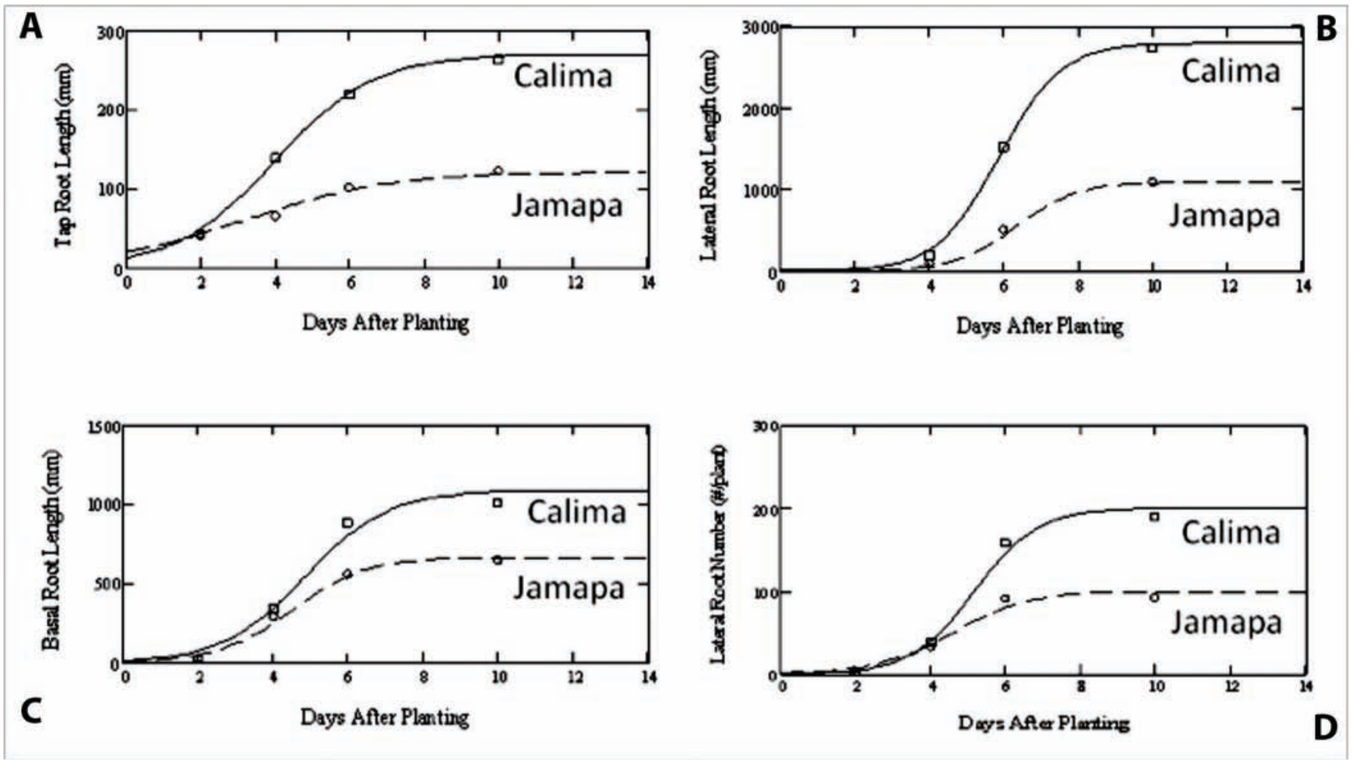


Figure 6. Logistic growth curves. A) Tap, B) Lateral, C) Basal Rootlengths, and D) Number of Lateral Roots of Calima and Jamapa seedlings.

ima and Jamapa, the period between the 4th and 6th day showed the greatest increase in the number and length of laterals. Unlike measurements that are performed at one time point, for instance the plateau, parameters obtained with the logistic curve are very descriptive of the growth pattern and can be used for analysis of the genes that control the growth trajectories of the different roots– a procedure also known as functional mapping (Ma et al. 2004).

The third type of rhizotron is called a Cigar Roll. This rhizotron was used to study responses to phosphorous levels in the root medium in the Andean landrace G19833, and Andean breeding line Calima and the Mesoamerican landrace Jamapa. The construction of this rhizotron is very simple. Following seed germination and the elongation of the radicle to approximately 5mm to 1 cm, the young seedling is rolled in a sheet of germination paper saturated with modified Hoagland solution containing either 2 mM or 0 mM PO4. The Cigar rolls are placed into a beaker containing nutrient 1solution (high or low P). Between nutrient treatments (once-a-week) the nutrient level was maintained to approximately 30 mm from the bottom of the cigar roll by adding deionized distilled H2O. The pH of the medium was adjusted every three days to 5.6 ± 0.2 with either KOH (1 mM) or HCL (1mM) during the growth period. Plants were grown at 25 ± 2 °C with a 12 hour photoperiod at ~150 µmol m-2 s-1 with cool white florescent lamps. Three plants were removed on days 2, 4, 6, 8, 10 and 14 days after planting. Fresh and dry weights were measured. Dry weight was obtained by drying the shoots (including the cotyledons) and roots for 48h at 60 °C. The first set of experiments was carried out to measure the effect of the cotyledons on early root growth. Figure 7 shows the accumulation of both fresh and dry weights of both shoot and roots of Jamapa and Calima during the first two weeks of growth. As expected from previous experiments, Calima displayed a faster growth rate than Jamapa for both the shoot and the root, particularly in fresh weight. However, growth analysis based on dry weight showed a significant decline in dry weight in Calima's shoot in contrast to a slight and almost imperceptible drop in Jamapa's shoot dry weight. This decline is mainly due to the transfer of carbon from the cotyledons to the roots. It can be seen in these graphs (Figure 7 C & D) that in contrast to Jamapa, Calima root growth takes priority

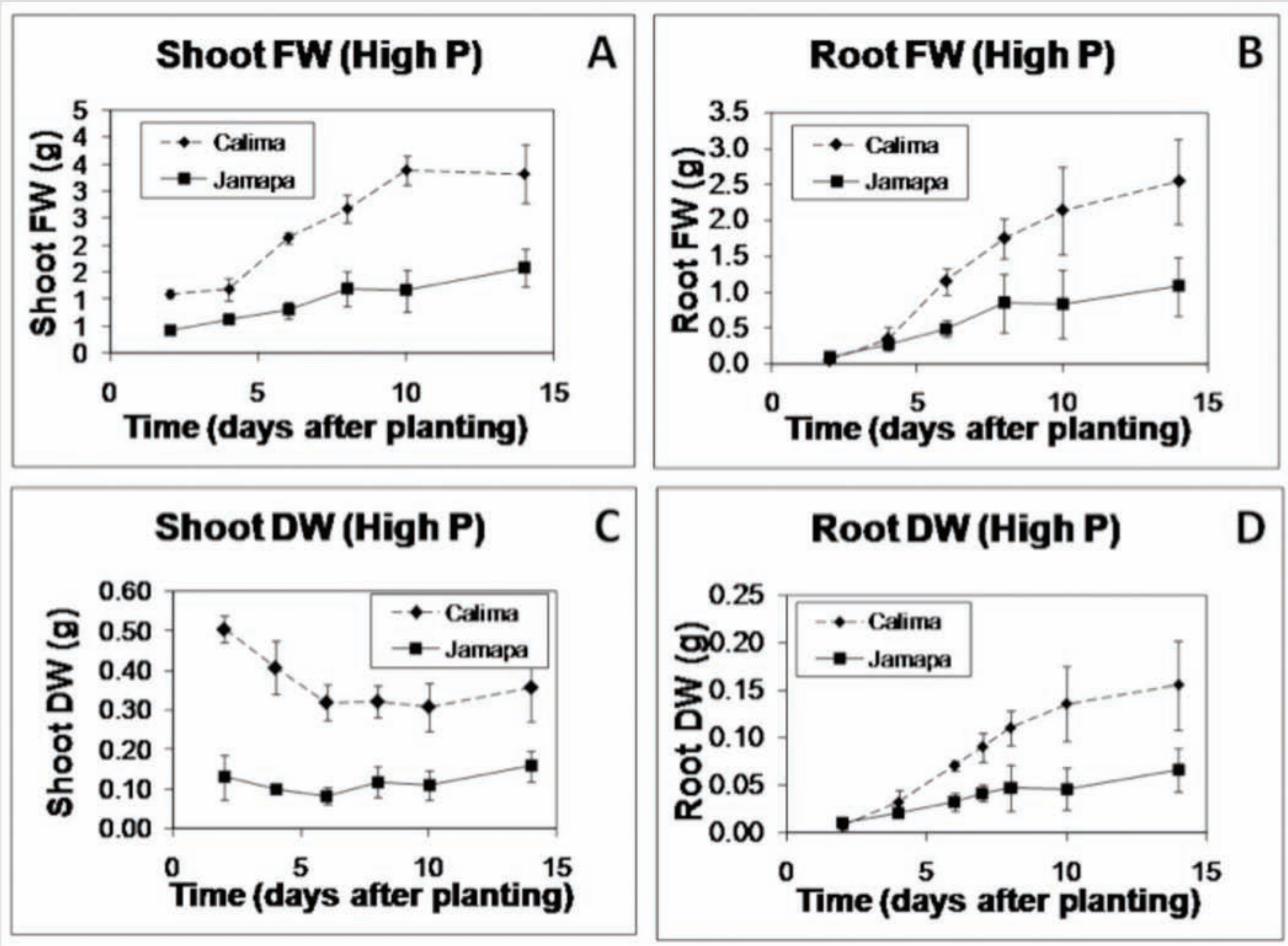


Figure 7. Shoot (A and C) and root (B and D) fresh (A and B) and dry(C and D) weight of two parental lines, Calima and Jamapa, after two weeks of growth in high phosphate (2 m M) using the Cigar Roll technique. Shoot dry weight includes the weight of the cotyledons.Values represent the mean of 3 samples (n = 3; ± Std Dev).

over shoot growth. In Jamapa, carbon allocation during this growth period is more evenly distributed between root and shoot. In practical terms, Calima would be expected to develop a more uniform stand under field conditions as it develops a root system better capable of resource acquisition than Jamapa. It remains to be determined whether the observed difference in growth pattern is entirely due to the dramatic difference in seed size (Calima's seed weigh is approximately 0.5g and Jamapa seed is 0.2 g), a differential adaptation strategy, or a combination of both.

Responses to phosphorous levels in the root media were investigated using the Cigar Roll rhizotrons. Figure 8 shows the pattern of dry weight accumulation of shoots and roots from Calima and Jamapa grown in the root media containing either 2 mM or 0 mM phosphate. These growth curves clearly show that phosphate levels have no effect on growth for the first two weeks of seedling growth of these beans. These results indicate that phosphorous reserves stored in the cotyledons completely satisfy the P-demand during early growth.

To confirm the role of cotyledons as a reliable source of phosphorus for the young seedling, a comparison of dry matter accumulation by the roots of G19833, Calima and Jamapa was carried out after three weeks under high P (2 mM) and low P (0 mM) levels. The roots of G19833 and Calima showed a significantly greater accumulation of dry

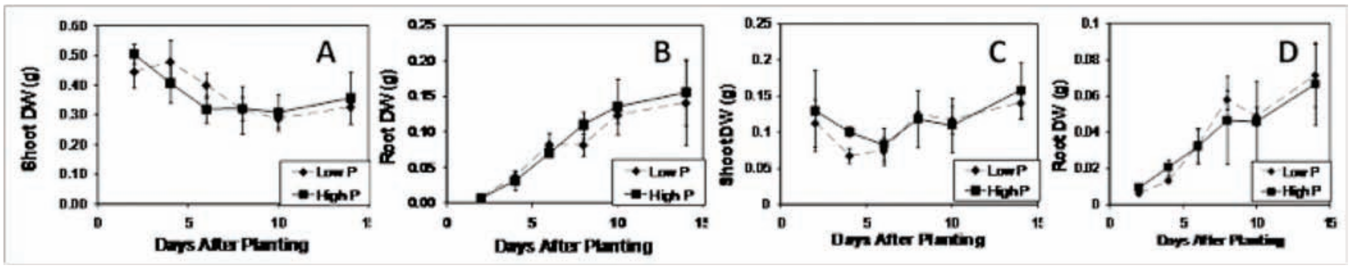


Figure 8. Dry matter accumulation in shoots (A & C) and roots (B &D) of Calima (A & B) and Jamapa (C & D)seedlings grown under two phosphate levels.

matter under the low P treatment than under high P conditions. In contrast, no significant differences were detected in Jamapa. There are two possible explanations for the results observed in Jamapa. Either this landrace is very efficient in utilizing traces of phosphorous in the root media, or it lacks the mechanism to sense low P levels and re-direct resources to the roots to increase surface area and P-uptake.

To assess the role played by cotyledons on the P-response of young seedling, the cotyledons were removed eight days after planting, and the seedlings were grown at high (2 mM) or low (0 mM) phosphate for a total of three weeks. Intact seedlings responded to P-levels as expected. G19833 and Calima allocated more assimilate to the roots under low P conditions than under control conditions, whereas Jamapa didn't appear to respond in a significant manner. Removal of the cotyledons eliminated the low-Phosphorous response in G19833 and Calima, but appeared to have a modest effect in Jamapa. It was expected that removal of the cotyledons would exacerbate the low P stress and enhance the carbon allocation to root. These results suggest that at least in the Andean accession the sensor for low P levels may be located temporarily in the cotyledons.

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

Development of PCR-based Markers for QTL Analysis

The BNG (BeaN Genomic markers) markers of the common bean have been previously mapped as RFLP probes. This technology is relatively expensive in terms of reagents and labor. A more efficient approach is the use of PCR-based markers. The strategy used was to sequence these markers and develop locus-specific PCR markers to amplify allelic sequences from Calima and Jamapa. These sequences can then be aligned with each other to identify informative polymorphisms. Allele-specific primes can then be developed based on these polymorphisms. Accordingly, 143 markers were sequenced using Sanger sequencing technology. This was carried out at the Sequencing Core Lab of the Interdisciplinary Center for Biotechnological Research, University of Florida. Sixty five markers were previously sequenced on a different project. This sequencing effort has produced a total of 307,000 bases. Clone sequences will be submitted to GenBank. Fifty of these sequences were analyzed and used to design primers to amplify allelic sequences from Calima and Jamapa. The allelic amplicons were then sequenced and their sequences compared to identify polymorphism. New allele-specific primers were developed for 48 of these marker loci. (Table 1)

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

Simulation of Jampa and Calima root responses to irrigation

The parental genotypes and their recombinant inbred family have been grown at the University of Puerto Rico in Mayagüez by Dr. James Beaver. Phenological and yield data for these genotypes have been made available to us for analysis. Computer simulations of root responses to irrigation have been generated for the parental genotypes using climate data from the Mayagüez Station in Puerto Rico. Figure 9 shows that Calima has a small advantage over Jamapa during the first three weeks, but this difference disappears

Table 1. List of BNG clones that have been sequenced in this project. The insert sizes are given in base pairs (bp) and the chromosome number assignation (Chr).

Marker	bp	Chr	Marker	bp	Chr	Marker	bp	Chr	Marker	bp	Chr
BNG001	1790	6	BNG065	2080	2	BNG116	1930	5	BNG174	2600	9
BNG002	1800	11	BNG067	2170	6	BNG117	1430	9	BNG176	3120	11
BNG004	1270	2	BNG068	2530	8	BNG118	1760	4	BNG179	2240	1
BNG005	1470	11	BNG070	1970	6	BNG119	2220	9	BNG180	2550	9
BNG007	2800	3	BNG071	2240	10	BNG120	1520	6	BNG181	1770	11
BNG009	4510	1	BNG072	3880	2	BNG121	1710	8	BNG187	1860	6
BNG010	4190	11	BNG073	2410	3	BNG123	1180	5	BNG188	1960	2
BNG011	3180	9	BNG075	1600	5	BNG126	2510	2	BNG189	2030	2
BNG012	2700	5	BNG076	3120	6	BNG128	2340	3	BNG191	2030	4
BNG013	1560	10	BNG077	2500	9	BNG129	1710	11	BNG193	2620	1
BNG014	3370	11	BNG078	2270	6	BNG133	3120	7	BNG195	2700	2
BNG015	3220	4	BNG079	2610	11	BNG134	3830	11	BNG197	2560	11
BNG016	2040	5	BNG082	1480	9	BNG135	3000	4	BNG198	2140	11
BNG019	2370	11	BNG083	870	2	BNG137	1710	1	BNG200	2340	8
BNG021	1980	5	BNG084	2190	9	BNG139	2540	3	BNG202	1620	1
BNG022	1780	3	BNG086	1650	5	BNG140	1780	11	BNG203	2990	4
BNG026	1960	1	BNG087	3350	1	BNG142	3470	5	BNG204	1420	4
BNG028	2110	4	BNG088	2510	1	BNG144	2220	9	BNG211	1810	4
BNG034	4330	9	BNG090	1850	9	BNG145	1930	6	BNG213	2180	3
BNG036	2500	2	BNG091	1470	6	BNG148	2220	9	BNG214	2330	3
BNG038	1800	3	BNG094	1460	1	BNG150	1940	11	BNG215	1350	1
BNG039	2300	2	BNG095	1580	1	BNG152	1070	7	BNG216	2040	5
BNG041	2780	2	BNG096	1140	3	BNG153	1900	4	BNG218	2020	8
BNG042	1500	4	BNG097	1380	6	BNG155	2810	5	BNG219	580	8
BNG046	2370	1	BNG098	1750	9	BNG158	2310	6	BNG220	4250	3
BNG047	2480	4	BNG100	2160	8	BNG159	3210	9	BNG221	2100	5
BNG048	1790	2	BNG102	1400	11	BNG160	2280	10	BNG222	2480	4
BNG052	1140	11	BNG104	1830	1	BNG161	1290	7	BNG223	2350	4
BNG055	1650	10	BNG106	2680	5	BNG162	590	7	BNG226	2220	11
BNG056	2480	11	BNG107	2560	4	BNG163	2180	11	BNG228	1840	11
BNG057	2090	9	BNG108	1540	9	BNG165	2260	5	BNG230	500	11
BNG058	2400	3	BNG109	1930	11	BNG166	2170	7	BNG231	2100	11
BNG060	2290	4	BNG111	1970	11	BNG168	2210	4	BNG232	1800	5
BNG061	1580	9	BNG112	820	6	BNG171	1900	2	BNG234	900	8
BNG062	2310	3	BNG114	1540	5	BNG172	3120	8	BNG235	2030	7
BNG064	1620	11	BNG115	1930	9	BNG173	2050	2			

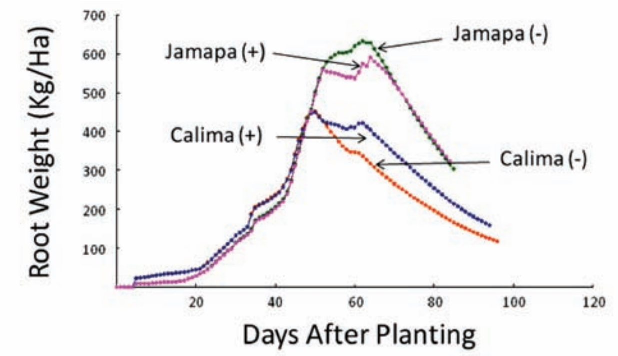


Figure 9. Computer simulation of root mass accumulation in the presence (+)and absence (-) of irrigation in Puerto Rico.

for the next month with no significant root responses to irrigation treatments, but a significant effect was detected afterwards. The slight advantage showed by Calima is an in agreement with our findings obtained with small seedlings grown in the rhizotrons. The difference in root mass accumulation that appears between Jamapa and Calima during the late stages of growth raises the question about whether these differences are correlated to the indeterminate growth habit of Jamapa, or are controlled independently by other genes with root specificity. Simulation of root densities showed (Figure 10) that Calima has higher root densities in the topsoil early in development, but Jamapa has greater densities later in development and at greater depths.

LESSONS LEARNED

We learned that a multidisciplinary approach to study roots was the best approach. It resulted in the development and implementation of methodologies to study root growth and development. These technologies include magnetic resonance imaging, computer image analysis, physiology, genetics and crop simulation. The ability to study intact roots in 2D and 3D settings has led to the identification of genetic variation of certain root traits, which are related to root growth rates and architecture and to responses to low phosphorous; traits that can be genetically manipulated to develop cultivars with improved water and phosphorous utilization efficiencies. This multidisciplinary approach allowed this research program to gain support from different sources. In one example, our collaboration with Dr. Stephen Blackband, from the Department of Neuroscience and also a scientist at the McKnight Brain Institute, was instrumental in the development of the protocol for obtaining magnetic resonance images of intact roots. In another, our work with Dr. Baba Vemuri from the Department of Computer and Information Science & Engineering, and also Director of the Center for Vision, Graphics & Medical Imaging, led to the development of the algorithms for processing and analyzing MRI root data. In another area, data made available from Dr. James Beaver, of the University of Puerto Rico, were used for computer simulation studies. Finally, the Department of Agricultural and Biological Engineering gave an assistantship to a graduate student who was responsible for collecting some of the 2D and 3D data.

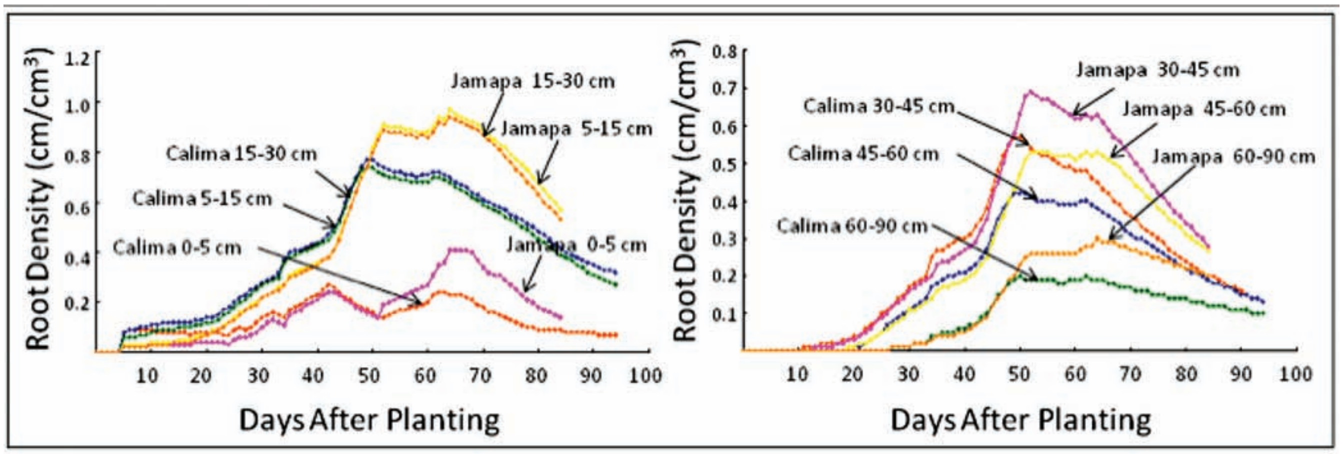


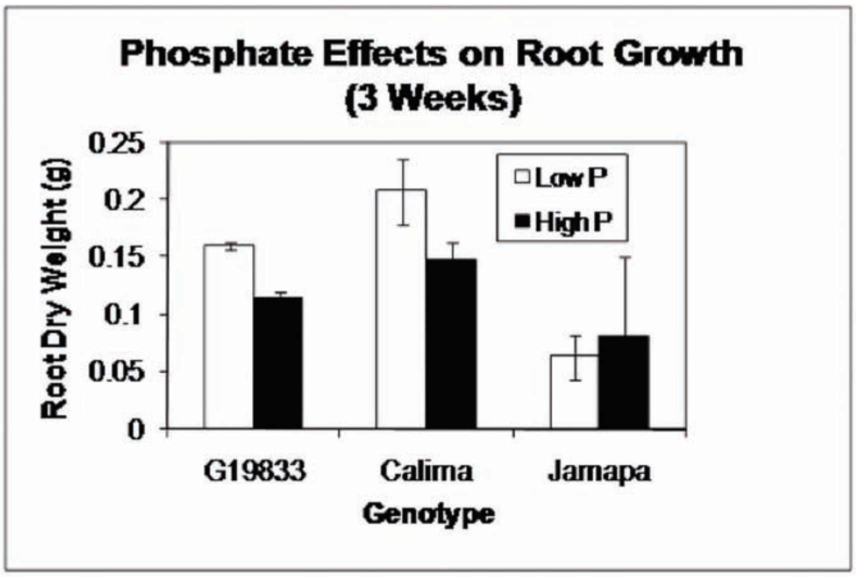
Figure 10. Computer simulation of root densities at different soil depths.

NEXT STEPS

The information obtained in this project will be used to map the root adaptive responses we have detected in the common bean genotypes that were analyzed. New generation DNA sequencing technologies (SOLiD from Applied Biosystems (http://solid.appliedbiosystems.com; Dressman et al. 2003; Shendure et al. 2005)) will be used in the future to identify more informative polymorphisms in on a massive scale at a fraction of the cost obtained with current Sanger sequencing technology.

The long range goal of this program was to first identify genes that control the root traits, tag them with molecular markers and then modify the existing crop model (BEAN-GRO) so it can use genotype data to predict the phenotype in a given range of environments including soil characteristics and management practices. Overall, we have achieved our goal to a great extent by developing the tools that will allow us to identify and genetically manipulate genes that control root growth and development.

Effect of phosphorous levels in the root media on carbon allocation to the roots.



PARTICIPATING AND COLLABORATING SCIENTISTS & INSTITUTIONS/ORGANIZATIONS

National Agricultural Research Systems (NARS)

Puerto Rico

University of Puerto Rico
James Beaver

United States

University of Florida
Stephen Blackband
Gary Blaskowski
Melanie Correll
James Jones
Xeve Silver
C. Eduardo Vallejos
Baba Vemuri

DEGREE PROGRAMS

Degree Programs

Year	Name	Degree	Gender	Institution	Home Country
2007	Yibing Fu	MSC	M	University of Florida	China

LITERATURE CITED

Dressman, D, H Yan, G Traverso, KW Kinzler, and B Vogelstein. 2003. Transforming single DNA molecules into fluorescent magnetic particles for detection and enumeration of genetic variations. Proc. Natl. Acad. Sci. USA 100: 8817-8822.

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PRESENTATION

Subakan O., B. Jian, B.C. Vemuri and C. E. Vallejos. 2007. Feature preserving image smoothing using a continuous mixture of tensors. Proc. Eleventh IEEE International Conference on Computer Vision ICCV07, 1-6.

Chapter Ten

Field Support to Missions

TIMOR-LESTE AGRICULTURAL REHABILITATION, ECONOMIC GROWTH AND NATURAL RESOURCE MANAGEMENT

GORO UEHARA, DEPARTMENT OF TROPICAL PLANT AND SOIL SCIENCES
UNIVERSITY OF HAWAII AT MANOA, HONOLULU, HI, USA

HAROLD MCARTHUR, OFFICE OF THE VICE CHANCELLOR FOR RESEARCH AND GRADUATE EDUCATION
UNIVERSITY OF HAWAII AT MANOA, HONOLULU, HI, USA

UNIVERSITY OF HAWAII

Vegetable production in Venilale (high elevation).

Table of Contents

Visitors at the MAFF nursery.

FSM: Timor-Leste – University of Hawaii

OVERVIEW & EXECUTIVE SUMMARY

Participating farmers in three agro-ecological zones within the Seical watershed in Timor-Leste were able to increase maize yields from 1.5 tonnes/ha to 4.8 tonnes/ha and rice yields from 2.0 tonnes/ha to 4.9 tonnes/ha. These increases were achieved not simply by adding fertilizer, but by enabling the T-L Ministry staff to diagnose nutrient deficiencies with soil test kits and eliminate the cause for the low crop yields.

The project recognized that the entrepreneurial spirit is alive and well in Timor-Leste, yet this human quality must be linked to the ecological characteristics of the land in order to exploit its resourcefulness. Aquaculture near the coastal zone, poultry and animal husbandry in the middle elevation and vegetable production in the cooler, upper elevations are income- and job-generating enterprises that can be developed in one watershed and replicated in other watersheds throughout the country (*see* photo on title page).

The importance of matching the biological requirements of an enterprise to the physical characteristics of the land was never more evident then with candlenut. The candlenut tree grows virtually everywhere in Timor-Leste, but more abundantly at the middle elevations. When the Timorese farmer deems the price is right, the nut is sold for export to Indonesia where it is used as a food condiment. The project was able to help identify a different export market. Now oil is extracted from candlenut and marketed internationally as an ingredient in cosmetics. This new market adds value to a local product, enabling businesses to generate new income and jobs. More importantly, rural households in Baucau can now earn new income by harvesting, processing and selling nut from trees that grow in and around their villages (Figure 1).

The importance of participatory stewardship was a lesson that can be learned by all. People who live by farming often fail to see the slow degradation of their land and surrounding environment and do not support efforts by outsiders to reverse the process. The project made the assumption that villagers and their leaders would support land conservation practices and policies if they had a voice in the design and implementation of activities, and especially if the people benefited from the outcomes. These conservation practices, such as growing privately owned teak trees that produce valuable timber or candlenut trees that produce marketable nuts, have a better chance of succeeding than large scale government-owned tree plantings, for example. Moreover, fast growing nitrogen fixing trees that provide fodder, fuel wood and income to households and at the same time improve soil quality by sequestering nitrogen-rich organic carbon in soils offer a way to protect and preserve the land for future generations.

This report also lists opportunities for future development, for in the end, the principal lesson learned is that agricultural rehabilitation is about enabling customers, whether they be farmers, Ministry of Agriculture personnel or policy makers to make better choices for themselves and for the society in which they live (*see* photo on opposite page).

PUBLICATION OF FINAL REPORT

The Timor-Leste final report was printed in September 2006. Only the Overview & Executive Summary from that report is printed here. A handful of copies are available at the SM CRSP offices at the University of Hawaii. It is also available for viewing and download at http://tpss.hawaii.edu/tl/.

Citation

Uehara, G., H. J. McArthur, J.B. Friday, M. Jones, R. M. Ogoshi, and G.Y. Tsuji. 2006. Timor-Leste Agricultural Rehabilitation, Economic Growth and Natural Resources Management. Final Report. SM CRSP/TPSS/CTAHR, University of Hawaii, Honolulu, Hawaii. 14 pp.

Figure 1. Oil-bearing candlenut.

Chapter Eleven

Field Support to Missions

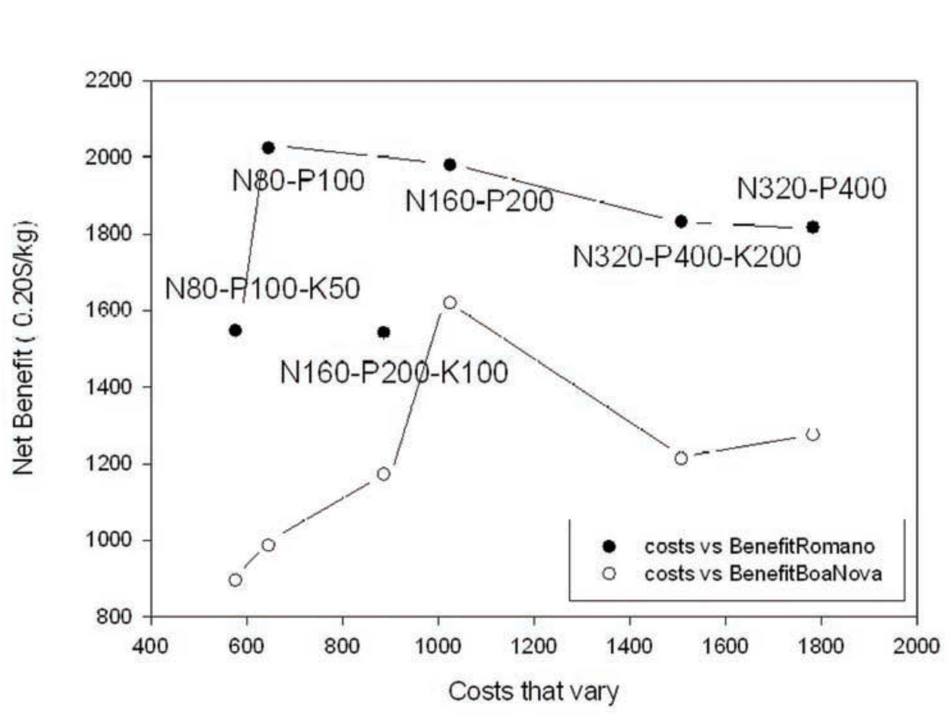
IMPROVING MAIZE PRODUCTIVITY IN THE PLANTANO AREA OF ANGOLA

RUSSELL YOST, DEPARTMENT OF TROPICAL PLANT AND SOIL SCIENCES
UNIVERSITY OF HAWAII AT MANOA, HONOLULU, HI, USA

UNIVERSITY OF HAWAII

Using NuMaSS for nutrient management prescription for farmers in Huambo, Angola.

Table of Contents



Economic dominance analysis for potato, Huambo, Angola.

OVERVIEW & EXECUTIVE SUMMARY

One objective of USAID/Angola was to stimulate the agriculture sector serve as a source of food security and engine for economic growth and development. To achieve that objective, the USAID mission in Luanda engaged the SM CRSP as a field support activity to provide a scientific and cost-effective basis for increasing maize production by ensuring that the right nutrients are applied to the right crop at the right time and in the right amounts.

To overcome low maize yields in the Planalto region where a million people are food insecure, the SM CRSP proposed using a participatory learning approach to stimulate interests among farmers and farmer organizations to determine their site-specific fertilizer requirements for maize production.

The site-specific nutrient management (SSNM) approach, developed by the SM CRSP Project and its collaborators, was introduced as a way to accomplish this by following step-wise structure: 1) diagnosis, 2) prescription, 3) economic analysis that includes farmer inputs, and 4) recommendation. This approach was validated in Thailand (Attanandana and Yost. 2003), the Philippines, and Mali prior to its introduction in Angola as reported in the chapter on NuMaSS. This farmer-empowering approach included training farmer leaders to use soil test kits so they could "diagnose" nutrient response situations in their fields, farms, or even problem sections of their fields. This structure empowered the farmer / grower and extension personnel with information to use simplified decision-aids to interpret and convert soil test kit values into amounts of specific fertilizers to economically solve the diagnosed problem.

Huambo, one of six provinces associated with the Planalto of Southern Angola was selected for technology introduction after an initial survey for potential and promising sites (*see* photo on title page).

Objective

Enable Angolan scientists to diagnose nutrient deficiencies and prescribe fertilizers to empower farmers to improve maize and potato productivity in Huambo and other Planalto provinces (*see* photo on opposite page).

Activities

The following steps were proposed to introduce the technology:

- Training and skill development of Angolan scientists, NGOs and farmer associations;
- Rapid assessment and identification of regions of high food production potential;
- Suggest data storage system for knowledge management by NARs;
- Establish regional field demonstrations with local scientists, farmer leaders and fertilizer dealers;
- Link fertilizer recommendations to agricultural marketing and input networks.

PROJECT ACCOMPLISHMENTS

Accomplishments from this activity were reported in Asanzi et al. (2006). In summary, information technology tools, such as decision aids and geospatial analysis, were introduced. Participatory methods of using soil test kits, farmer-to-farmer visit, and farmer empowerment were used to illustrate that the country and its scientists can "leapfrog" into use of current technology and knowledge management skills if they so choose. Maize yields of up to 9000 kg/ha and potato yields as high as 16,000 kg/ha were obtained during the cool, dry season. Indications are that irrigation is available during the dry season, potentially providing sustainable water supply for year round irrigation. Soils from the experimental sites were characterized using Soil Taxonomy (Soil Survey Staff, 1999) to facilitate sharing of production system technology and expertise.

PUBLICATIONS, PRESENTATIONS AND REPORTS

Asanzi, C., D. Kiala, J. Cesar, K. Lyvers, A. Querido, C. Smith, and R.S. Yost. 2006. Food production in the Planalto of Southern Angola. Soil Sci. 171(10):810-820.

Attanandana, T. and R. S. Yost. 2003. A site-specific nutrient management approach for maize. Thailand's experience. Better Crops International. 17:3-7.

Soil Survey Staff. 1999. Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys, 2nd edition, U.S. Department of Agriculture, Washington, D.C.

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 following individuals were part of the Management Entity's administrative staff over the life of the Grant. They include in alphabetical order,
Marilyn DeVera, Secretary
Mieko MacLachlan, Administrative Coordinator
Sharon Horie, Secretary
Agnes Shimamura, Fiscal Specialist
Eric Ikawa, Webmaster
Doris Victor, Office Associate
Pamela McKemy, Secretary
Xiang-li Xu, Computer Programmer

The following individuals provided editorial, writing and video and graphical support to the Management Entity on a contractual basis over the life of the Grant.
Sharon Balas, Editor/Designer
Keith Bing, Videographer/Producer

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

PARTICIPATING ENTITIES

Board of Directors (BOD)

The CRSP Guidelines states: "The Board consists of representatives or all of the participating institutions and may include individuals from other organizations and host country institutions. The AID Program Officer and the ME Director serve as ex-officio members. The institution, which serves

James Tiedje and Will Blackburn of the EEP and Harrison Akortsu, farmer, near Kpeve, Ghana.

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 from 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

Meetings of members were held periodically as necessary to address administrative and technical issues as determined by the ME in consultation with the Board chair.

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:

Dr. E.B. (Ron) Knapp, CIAT (retired), **Chair**
Dr. Thomas Walker, CIP and Michigan State University (retired).
Dr. John Antle, Montana State University
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 socioeconomic 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 in-

Ron Knapp, chair of the TC.

clude 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 include:

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 in 2006. Dr. Amit Roy was unable to participate due to his responsibilities at IFDC. 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 the EGAT/NRM director, Dr. David Hess.

USAID/CTO

Charles Sloger from the Office of Agriculture in EGAT was CTO during the first phase (1997-2002) and from 2002 to 2005 in the second phase. From 2005 to 2007, Mike McGahuey, Jr. of the Natural Resources Management (NRM) division in EGAT served as the 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 project year (PY)10 ended in 2007, the SM CRSP and three other CRSP programs were moved back from NRM to the agriculture (AGR) within EGAT. With that move, Adam Reinhart became the CTO for the SM CRSP during the no-cost extension period in 2008.

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 include:

Eric Craswell, EEP chair, on site visit to Rangpur, Bangladesh.

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/

Fiscal Summary

The award total under the SM CRSP Grant from 1997 to 2008 was $31,672,428. Of that total, the SM CRSP received 13 percent or $4,040,000 from USAID missions and the Office of Disaster Relief. Cost of the Management Entity was $4,373,545 or 14% of the total. Expenditures and cost sharing figures will be reported in a separate report from the University of Hawaii to USAID.

Phase 1: 1997-2002

Project	***Institution***	***Award***
NifTAL	University of Hawaii	937,383
Tropical Steeplands	Texas A & M University	1,593,607
Gender and Soil Fertility	University of Florida	340,236
NuMaSS	North Carolina State University	4,841,624
Tradeoff Analysis	Montana State University	982,511
Rice-Wheat Systems	Cornell University	2,614,846
Field Support (Bangladesh)	Cornell University	1,000,000
Field Support (Ethiopia)	University of Hawaii	300,000
Field Supp (USAID*)	University of Florida	200,000
Management Entity	University of Hawaii	2,145,221
Phase 1		**14,955,428**

**Office of Disaster Relief*

Phase 2: 2002-2008

Carbon Sequestration	Cornell University	1,338,410
Carbon Sequestration	University of Florida	1,414,266
Carbon Sequestration	University of Hawaii	1,351,082
NuMaSS	North Carolina State University	1,220,680
NuMaSS	University of Hawaii	1,694,308
Tradeoff Analysis	Montana State University	2,696,931
Rice-Wheat Systems	Cornell University	1,595,069
Biotechnology	Cornell University	464,968
Biotechnology	University of Florida	172,962
Field Support (Angola)	University of Hawaii	140,000
Field Support (Timor-Leste)	University of Hawaii	2,400,000
Management Entity	University of Hawaii	2,228,324
Phase 2		**16,717,000**

Total Award		**31,672,428**

Acronyms

AB-DLO	Research Institute for Agrobiology and Soil Fertility, the Netherlands
ACN	Aménagements en courbes de niveau; aka, ridge tillage
AMF	Arbuscular mycorrhizae fungi
BAME	Bureau d' Analysis Macroeconomique
BARI	Bangladesh Agriculture Research Institute
BAU	Bangladesh Agricultural University
BRAC	Bangladesh Rural Advancement Committee – Bangladesh NGO
BRRI	Bangladesh Rice Research Institute
Bt	Bacillus thuringiensis
C	Carbon
CARE	An International NGO
CCX	Chicago Climate Exchange
CEMS	Carbon Enhancing Management System
CIAT	International Center for Tropical Research
CIAT-MIS	International Tropical Agriculture Center-Integrated Steepland Management
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
CRSP	Collaborative Research Support Program
CRW	Corn root worm
CSD	Chinese seed drill
CT	Conventional tillage
CURLA	Regional University Center for the Atlantic Coast
DADO	District Agricultural Development Office (Nepal)
DAE	Department of Agricultural Extension (Bangladesh)
DFID	Department for International Development (U.K.)
DICTA	Agricultural Science and Technology Directorate
DNA	Deoxyribonucleic acid
DSR	direct seeded rice
DT	Deep tillage
EEG	Easily Extractable Glomalin
EMBRAPA-CNPGC	Brazilian Agricultural Research Enterprise-National Beef Cattle Research Center
EMBRAPA-CPATU	Brazilian Agricultural Research Enterprise-Humid Tropics Research Center
ENEA	Ecole National d'Economie Applique
EnKF	Ensemble Kalman Filter
ETC	Educate the Children – Nepal NGO
FAO	Food and Agriculture Organization, United Nations
FFS	Farmer Field School
FYM	Farm yard manure
GCM	Global circulation model
GIS	Geographic Information Systems
GTZ	Deutsche Gesellschaft fur Technische Zusammenarbeit
GPS	Global Positioning System
HUM	Humus
IAAS	Institute for Agriculture and Animal Science
IC	Inter-Cooperation, International NGO (Swiss)
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Ag Research in Dry Areas, Syria
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDE	International Development Enterprise, an International NGO
IDIAP	Panama Agricultural Research Institute
IFAD	International Fund for Agricultural Development
IGP	Indo-Gangetic Plains
INIA	Instituto Nacional des Investigacoes Agricõlas
INIAP	National Agricultural Research Institute, Ecuador
INIFAP	National Forestry and Agricultural Research Institute, Mexico
INPOFOS	Potash & Phosphate Institute
INTA	National Agricultural Technology Institute, Nicaragua
IRRI	International Rice Research Institute
ISRA	Institut Senegalais de Recherche Agricole, Senegal
ITC	Candelaria Community Technical Institute, Honduras
ITS	Internal transcribe spacer

KU	Kasetsart University, Thailand
LOI	Loss on ignition method of carbon analysis
LTFE	Long-term soil fertility experiment
MOA	Ministry of Agriculture (Thailand)
MOU	Memorandum of Understanding
MRI	Magnetic Resonance Imaging
N	Nitrogen
NARC	Nepal Agriculture Research Council
NARES	National Agricultural and Extension Systems
NARI	National Agricultural Research Institute, The Gambia
NARS	National Agricultural Research Scien tists
NDVI	Normalized Difference Vegetation Index
NEMA	National Environmental Management Agency of Uganda
NGO	Non Governmental Organization
NMR	Nuclear Magnetic Resonance
NGOs	Non-Governmental Organizations
NT	Normal Tillage
NuMaSS	Nutrient Management Support System
NUTMON	Nutrient Monitoring Project
OC	Organic Carbon
PARC	Pakistan Agricultural Research Council
PAU	Punjab Agricultural University, Ludhi ana, India
PCR	Polymerase chain reaction
PES	Payment for environmental service
PROINPA	Andean Products Research and Promo-tion, Bolivia
QTL	Quantitative Trait Loci
RDRS	Rangpur Dinajpur Rural Service – Bangladesh NGO
RI	Recombinant Inbred
RMSE	Root mean square error
rRNA	Ribosomal ribonucleic acid
RWC	Rice-Wheat Consortium for the Indo-Gangetic Plain
SEPA	Sementes de Papa, Bolivia
SM CRSP	Soil Management Collaborative Research Support Program
SNP	Single-Nucleotide Polymorphism
SOC	Soil organic carbon
SOM	Soil organic matter
SS	Surface seeding
STS	Sequence-Tagged Site
TAES	Texas Agricultural Experiment Sta-tion
TDR	Time Domain Reflectometry
TOA	Tradeoff Analysis
TOC	Total organic carbon
TPR	Transplanted rice
T-RFLP	Terminal Restriction Fragment Length Polymorphism
TSN	Total soil nitrogen
TSP	Total soil phosphorus
UCA	Central American University, Nicaragua
UCR	University of Costa Rica
UNA-Catacamas	National Agricultural University, Honduras
UNA-Nicaragua	National Agrarian University, Nicaragua
UNIDERP	University for Development of the State and Region of the Pantanal, Campo Grande, MS, Brazil
WB	Walkley-Black method for carbon determination
WINROCK	Winthrop Rockefeller Foundation, an International NGO
WUR	Wageningen Agricultural Univer-sity and Research Center
ZT	Zero tillage (surface seeding)

Contact Information

NUMASS - UH

Russell Yost: rsyost@hawaii.edu
Tasnee Attanandana: tasnee_attanan@yahoo.com
Madonna Casimero: mcasimero@philrice.gov.ph

NUMASS - NCSU

T. Jot Smyth: jot_smyth@ncsu.edu
Deanna L. Osmond: deanna_osmond@ncsu.edu

TRADEOFF ANALYSIS - MSU

John M. Antle: jantle@montana.edu

RICE-WHEAT SYSTEMS - CU

John M. Duxbury: jmd17@cornell.edu
Julie G. Lauren: jgl5@cornell.edu

CARBON SEQUESTRATION - UH

Russell Yost: rsyost@hawaii.edu

CARBON SEQUESTRATION - UF

James W. Jones: jimj@ufl.edu

CARBON SEQUESTRATION - CU

John M. Duxbury: jmd17@cornell.edu
Julie G. Lauren: jgl5@cornell.edu

BIOTECHNOLOGY - CU

Medha Devare: mhd6@cornell.edu
Janice Thies: jet25@cornell.edu
John M. Duxbury: jmd17@cornell.edu

BIOTECHNOLOGY - UF

C.Eduardo Vallejos: vallejos@ufl.edu
James W. Jones: jimj@ufl.edu
Melanie Correll: correllm@ufl.edu

FIELD SUPPORT - TIMOR-LESTE

Goro Uehara: goro@hawaii.edu
Harold McArthur: hmcarthu@hawaii.edu

FIELD SUPPORT - ANGOLA

Russell Yost: rsyost@hawaii.edu