TSBF Institute

Project PE-2: Integrated Soil Fertility Management in the Tropics

ANNUAL REPORT 2006

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

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PROJECT PE-2:
INTEGRATED SOIL FERTILITY MANAGEMENT IN THE TROPICS

Annual Report 2006

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Integrated Soil Fertility Management in the Tropics

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OUTLINE OF THE REPORT

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Published work

Completed work

Completed work

Output targets 2007

1. TSBF-CIAT RESEARCH FOR DEVELOPMENT STRATEGY

A. Research for development strategy of TSBF-CIAT

The 2005-2010 TSBF-CIAT strategy is aligned with the **Millennium Development goal:** "to help create an expanded vision of development that vigorously promotes human development as the key to sustaining social and economic progress in all countries, and recognizes the importance of creating a global partnership for development." The strategy encompasses the **CGIAR's agriculture and environment mission:** "to contribute to food security and poverty alleviation in developing countries through research, partnerships, capacity building and policy support, promoting sustainable agricultural development based on environmental sound management of natural resources." The strategy is also aligned with the CIAT's three research for development challenges: 1) improving management of agroecosystems in the tropics; 2) rural innovation research; and 3) enhancing and sharing the benefits of agrobiodiversity.

TSBF-CIAT's Program has three main goals. These are: (1) to strengthen national and international capacity to manage tropical ecosystems sustainably for human well-being, with a particular focus on soil, biodiversity and primary production; (2) to reduce hunger and poverty in the tropical areas of Africa and Latin America through scientific research leading to new technology and knowledge; and (3) to ensure environmental sustainability through research on the biology and fertility of tropical soils, targeted interventions, building scientific capability and contributions to policy.
TSBF-CIAT utilizes a range of approaches to achieve program goals in collaboration with its partners, with particular emphasis on the following:

Catalysis: Ensuring that partners are kept at the forefront of conceptual and methodological advances by conducting and promoting review, synthesis and dissemination of knowledge. This is done through workshops, training courses and sabbatical and short exchange visits.

Collaboration**:** Developing appropriate alliances with institutions across the research, educational and developmental spectrum, including linkages between institutions in the North and South.

Facilitation**:** Coordinating actions among partners to achieve progress and success in research. This is done by providing backstopping support in the preparation, submission, implementation and publication of research projects.

Conviction: Demonstrating tangible results by taking policy makers to the fields.

Internal and external reviews of the program**:** The Institute's activities and outputs undergo periodic critical reviews to ensure high standards and the achievement of the Institute's mission.

Since its founding in 1984, TSBF has conducted research on the role of biological and organic resources in tropical soil biology and fertility, in order to provide farmers with improved soil management practices to sustainably increase agricultural productivity. In recent years, TSBF-CIAT's research for development approach has been based on an Integrated Soil Fertility Management (ISFM) paradigm. ISFM is a holistic approach to soil fertility research that embraces the full range of driving factors and consequences of soil degradation — biological, physical, chemical, social, economic and political.

However, successful resource management and sustainable agricultural productivity need to go still further, into the realms of markets, health and policies (Figure 1). The central hypothesis is that natural resource management research will have more leverage if the apparent gaps between investment in the natural resource base and income generation can be bridged. Therefore, TSBF-CIAT's strategy proposes to take ISFM an additional step forward, by addressing the full chain of interactions from resources to production systems to markets and polices. Under the new framework, investment in soil fertility management represents a key entry point to agricultural productivity growth, and a necessary condition for obtaining positive net returns to other types of farm investments.

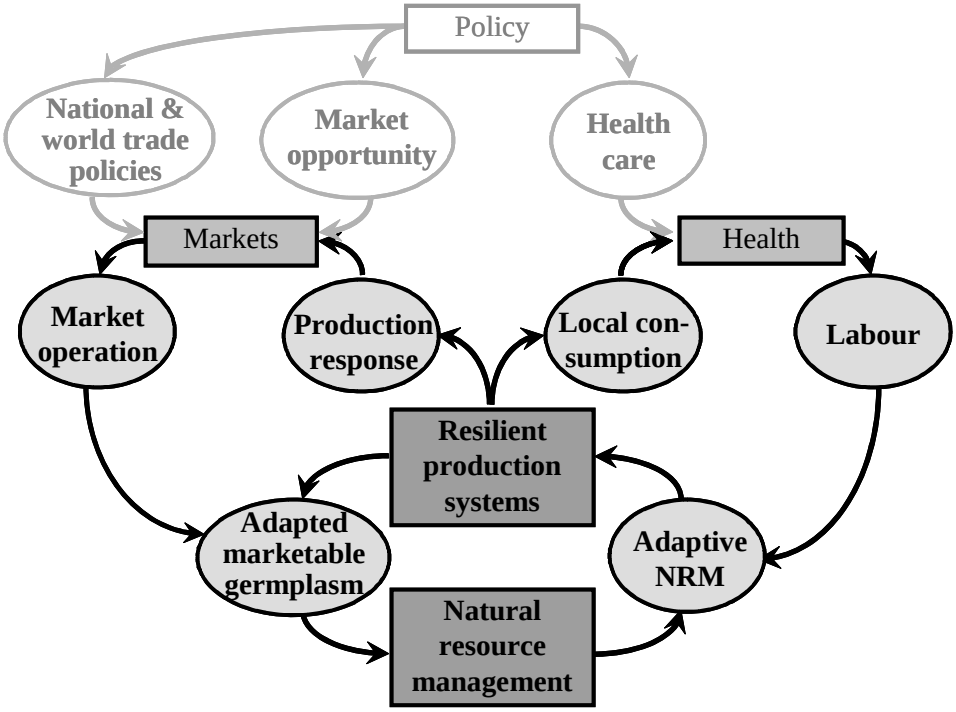

Figure 1. Conceptual framework of the TSBF-CIAT strategy. Topics in bold indicate the driving forces to be addressed by the proposed strategy; topics in shaded lighter gray are driving forces beyond the control of the Program.

TSBF-CIAT will pursue the following three major objectives under its strategy:

- ü to improve the livelihoods of people reliant on agriculture by developing profitable, socially-acceptable and resilient agricultural production systems based on ISFM;
- ü to develop sustainable land management (SLM) practices in tropical areas while reversing land degradation; and
- ü to build the human and social capital of all TSBF-CIAT stakeholders for research and management on the sustainable use of tropical soils.

To achieve these objectives, TSBF-CIAT's work is organized into five major outputs:

1. Biophysical and socioeconomic processes understood, principles, concepts and methods developed for protecting and improving the health and fertility of soils;
2. Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical, socio-cultural and economic processes;
3. Partnerships and tools developed and capacity enhanced of all stakeholders for improving the ealth and fertility of soils;
4. Improved rural livelihoods through sustainable, profitable, diverse and intensive agricultural production systems;
5. Options for sustainable land management (SLM) for social profitability developed, with special emphasis on reversing land degradation.

Each of these outputs has specific output targets for each year to contribute towards output level outcomes and output level impacts. The outcomes and impacts are conceptualized using seven strategic pillars:

1. Improving fertilizer efficiency and developing soil and water management practices;
2. Improved germplasm as an entry point for managing soil fertility;
3. Managing the genetic resources of soil for enhanced productivity and plant health;
4. Understanding farm level social dynamics;
5. Linking farmers to markets, nutrition, and health;
6. NRM strategies to move from plot to landscape scales; and
7. Strengthening scientific and institutional capacity of partners for integrated soil fertility management.

TSBF-CIAT's strategy has a major focus on developing and extending technologies that support sustainable intensification of cropping systems, especially in the dry and moist savanna, hillside, and forest and forest margin agro-ecological zones (AEZs) in Africa and Latin America. In these AEZs, poverty, population growth and a rising demand for food is driving expansion of cropped area into increasingly marginal lands and/or remnant forest zones. Under these circumstances, sustainable intensification of agriculture on already cultivated land represents the most promising solution to achieving food security and protecting against natural resource degradation, the ultimate goals of TSBF-CIAT's work.

As a relatively small research institute, it is important that TSBF-CIAT position itself appropriately on the research-development continuum. TSBF-CIAT's primary role and comparative advantage is in conducting international public goods research on ISFM in farming systems where soil degradation undermines local livelihoods and market opportunities. However, while TSBF-CIAT will focus primarily on strategic research, it is also ready to support technology dissemination and development activities with partners via regional networks and global projects. TSBF-CIAT will continue research on below-ground biodiversity as a means of beneficially managing soil biology, through the GEF-UNEP funded global project on below-ground biodiversity (BGBD) which has successfully completed its Phase I and is about to start its Phase II activities.

Much of the applied research and dissemination of findings, as well as NARSs capacity building, will be done via the Institute's two partner networks — the African Network for Soil Biology and Fertility (AfNet), and the Latin American Consortium on Integrated Soil Management (known by its Spanish acronym, MIS). TSBF-CIAT also collaborates with the South Asian Regional Network (SARNet) on soil fertility research in that region.

To carry out the work envisioned under the new strategy, the following staff positions will be called for:

Agrobiophysical scientists: These include specialists in integrated soil fertility management, soil biota management, soil and water conservation, ecosystem services, microbiology, and plant nutrition and physiology.

Social scientists (including agricultural economics): This staff category will be strengthened to permit greater emphasis on the socio-economic aspects of the new research paradigm.

Coordination: This includes the Institute Director, coordinators of the AfNet and MIS networks, and the coordinator of the GEF-UNEP Below Ground Biodiversity Project.

Funding: The estimated funding required for TSBF-CIAT's work is approximately US$5 million per year, for a total budget of about $25 million over the next 5 years.

B. Organization of the report

This annual report for 2006 is organized with the following sections. It starts with a brief summary of the strategy of the TSBF-CIAT followed by a brief description of the project and its logfrme that includes the 5 outputs, output targets for each output, outcomes and impacts at each output level as described in the CIAT Medium-Term Plan 2007-2009. This is followed with a section on research highlights organized according to the 5 outputs. The full report is organized by 5 major outputs of the project. Each output report contains its rationale, key research questions, highlights of research and specific output targets for the years 2007, 2008 and 2009. For each output target, the published work is reported as abstracts from refereed journal articles that were published in the year 2006. This is followed by the completed and on-going research activities that are related to each output target. Progress towards output level outcomes and output level impacts are summarized at the end of the report for each output. Information on list of staff, list of students, list of partners and list of publications is included in the Annexes section.

C. Project outputs and their link to strategy

The project has 5 major outputs. Output 1 (Biophysical and socioeconomic processes understood, priciples and concepts developed for protecting and improving the health and fertility of soils) involves research to develop principles and concepts that transcend the classical boundaries of the biophysical sciences and require integration with economics, sociology and anthropology. Integration of local and scientific knowledge to develop integrated "hybrid"knowledge and therefore could increase relevance to an overall strategy for sustainable soil management for improved food security and environmental protection.

Process and integrated knowledge generated from the research activities in output 1 needs to be translated into sustainable soil fertility and land management practices, adapted to the socio-cultural and economic environment in which these practices will be implemented. Research activities from Output 2 (Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical and socioeconomic processes) are expected to enhance farmers' capacity to translate best principles for soil, water and land management into practices that are appropriate to their environment and decision aids, condensing that knowledge for dissemination beyond the sites where this knowledge has been generated.

Managing soil fertility for improved livelihoods requires an approach that integrates technical, social, economic and policy issues at multiple scales. To overcome this complexity, research and extension staff need the capacity to generate and share information that will be relevant to other stakeholders working at different scales (i.e., policy makers, farmers). Thus the research activities in output 3 (Partnerships and tools developed and capacity enhanced of all stakeholders for improving the health and fertility of soils) are founded on building the human and social capital of all TSBF-CIAT stakeholders, research and management on the sustainable use of tropical soils.

Research activities of output 4 (Improved rural livelihoods through sustainable, profitable, diverse and intensive agricultural production systems) address the challenge of intensification and diversification of smallholder agricultural production that is needed to meet the food and income needs of the poor and cannot occur without investment in natural resource management, especially soil fertility. Investment in improving soil fertility is not constrained by a lack of technical solutions *per se* but is more linked to lack of access to information for improved decision making and analyzing trade-offs, inputs and profitable markets.

Soils play a central role for the provision of ecosystem services such as regulation of water quality and quantity, carbon storage and control of net fluxes of greenhouse gases to the atmosphere. Appropriate soil management could result in enhanced provision of environmental services. The major objective of research activities of output 5 (Options for sustainable land management (SLM) practices for social profitability developed, with special emphasis on reversing land degradation**)** is to restore degraded agroecologies to economic and ecological productivity by generating technology, institutional and policy innovations that restore degraded agricultural lands, enhance ecosystem health and improve livelihoods.

2. PROJECT DESCRIPTION AND LOGFRAME

CIAT PROJECT PE-2: INTEGRATED SOIL FERTILITY MANAGEMENT IN THE TROPICS

PROJECT DESCRIPTION

Goal: To strengthen national and international **capacity** to manage tropical ecosystems sustainably for human well-being, with a particular focus on soil, biodiversity and primary production; to reduce **hunger and poverty** in the tropical areas of Africa and Latin America through scientific research leading to new technology and knowledge; and to ensure **environmental sustainability** through research on the biology and fertility of tropical soils, targeted interventions, building scientific capability and contributions to policy.

Objective: To support the livelihoods of people reliant on agriculture by developing profitable, socially-just and resilient agricultural **production systems** based on Integrated Soil Fertility Management (ISFM); to develop **Sustainable Land Management** (SLM) in tropical areas of Africa and Latin America through reversing land degradation; and to build the **human and social capital** of all TSBF-CIAT stakeholders for research and management on the sustainable use of tropical soils.

Rationale and Changes

Rationale:

Soil fertility degradation has been described as one of the major constraints to food security and income generation in developing countries. Despite proposals for a diversity of solutions and the investment of time and resources by a wide range of institutions it continues to prove a substantially pervasive problem. The rural poor are often trapped in a vicious poverty cycle between land degradation, fuelled by the lack of relevant knowledge or appropriate technologies to generate adequate income and opportunities to overcome land degradation. Intensification and diversification of agricultural production on smallholdings is required to meet the food and income needs of the poor, and this cannot occur without investment in soil fertility. Investing in soil fertility management is necessary to help households mitigate many of the characteristics of poverty, for example by improving the quantity and quality of food, income, and resilience of soil productive capacity to environmental change.

The integrated soil fertility management (ISFM) is a holistic approach to soil fertility research that embraces the full range of driving factors and consequences of soil degradation — biological, physical, chemical, social, economic and political. There is a strong emphasis in ISFM research on understanding and seeking to manage the processes that contribute to changes in soil fertility. The emergence of this paradigm, very closely related to the wider concepts of integrated natural resource management (INRM), represents a significant step beyond the earlier, narrower, nutrient replenishment approach to soil fertility enhancement.

Research on natural resource management has been criticized for not addressing the real needs of rural people and hence has often been judged irrelevant. In the march to generate solutions to farmers' problems, research has generated a wide variety of technologies, such as fertilizers, improved legume germplasm and crop rotations. ISFM arose because of the recognition that addressing the ***interactions*** between components (e.g., water, pests and soils) is as important as dealing with the components themselves. However, improving the natural resource base without addressing issues of marketing and income generation (e.g. the resource-to-consumption logic) seems sterile and is often the reason for a lack of adoption of improved farming practices.

To address the soil fertility related issues and to contribute to sustainable land management in the tropics, the research for development portfolio of CIAT includes the Mega Project entitled "Integrated soil fertility management in the tropics" which is housed in the Research for Development Challenge "Improving Management of Agroecosystems in the Tropics". The goal of the project is to strengthen national and international capacity to manage tropical ecosystems sustainably for human well-being, with a particular focus on soil, biodiversity and primary production; to reduce hunger and poverty in the tropical areas of Africa and Latin America through scientific research leading to new technology and knowledge; and to ensure environmental sustainability through research on the biology and fertility of tropical soils, targeted interventions, building scientific capability and contributions to policy. The main objectives are: (1) to support the livelihoods of people reliant on agriculture by developing profitable, socially-just and resilient agricultural production systems based on Integrated Soil Fertility Management (ISFM); (2) to develop Sustainable Land Management (SLM) in tropical areas of Africa and Latin America through reversing land degradation; and (3) to build the human and social capital of all TSBF-CIAT stakeholders for research and management on the sustainable use of tropical soils.

To achieve these objectives, the work is organized into five major outputs:
1. Biophysical and socioeconomic processes understood, principles, concepts and methods developed for protecting and improving the health and fertility of soils;
2. Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical, socio-cultural and economic processes;
3. Partnerships and tools developed and capacity enhanced of all stakeholders for improving the health and fertility of soils;
4. Improved rural livelihoods through sustainable, profitable, diverse and intensive agricultural production systems;
5. Options for sustainable land management (SLM) for social profitability developed, with special emphasis on reversing land degradation.

Each of these outputs has specific output targets for each year to contribute towards output level outcomes and output level impacts. The outcomes and impacts are conceptualized using seven strategic pillars:
1. Improving fertilizer efficiency and developing soil and water management practices;
2. Improved germplasm as an entry point for managing soil fertility;
3. Managing the genetic resources of soil for enhanced productivity and plant health;
4. Understanding farm level social dynamics;
5. Linking farmers to markets, nutrition, and health;
6. NRM strategies to move from plot to landscape scales; and
7. Strengthening scientific and institutional capacity of partners for integrated soil fertility management.

The project has a major focus on developing and extending technologies that support sustainable intensification of cropping systems, especially in the dry and moist savanna, hillside, and forest and forest margin agro-ecological zones (AEZs) in Africa and Latin America. In these AEZs, poverty, population growth and a rising demand for food is driving expansion of cropped area into increasingly marginal lands and/or remnant forest zones. Under these circumstances, sustainable intensification of agriculture on already cultivated land represents the most promising solution to achieving food security and protecting against natural resource degradation.

Changes:
In the absence of identification of core support to CIAT by donors research on soils in Latin America has been largely phased out. This included the elimination of 3 senior staff positions (Soil Physics, Soil Ecology and Biodiversity, Systems Agronomy) and 13 support staff positions in the TSBF-Latin America team during 2006, and the departure of two senior staff positions (Ecosystem Services and

GIS/Agronomy). Because of this drastic reduction in core support, the output targets for 2007 and 2008 for the work in Latin America have been revised and scaled down.

CGIAR System Priorities:

CIAT's PE-2 Project (TSBF Institute) on Integrated Soil Fertility Management in the Tropics is housed mainly under CGIAR System Priority Area 4: Promoting poverty alleviation and sustainable management of water, land, and forest resources. Majority of the efforts are dedicated to System Priority Area 4A: Promoting integrated land, water and forest management at landscape level. The project contributes to Specific goals 1 (To develop analytical methods and tools for the management of multiple use landscapes with a focus on sustainable productivity enhancement), 2 (To enhance the management of landscapes through changing stakeholder awareness and capacity for social-ecological planning at landscape and farm levels) and 5 (Creating multiple benefits and improved governance of environmental resources through the harmonization of inter-sectoral policies and institutions). Considerable efforts are also dedicated to System Priority Area 4D: Promoting sustainable agro-ecological intensification in low- and high-potential areas. The project contributes to Specific goals 1 (To improve understanding of degradation thresholds and irreversibility, and the conditions necessary for success in low productivity areas), 3 (To identify domains of potential adoption and improvement of technologies for improving soil productivity, preventing degradation and for rehabilitating degraded lands), 5 (To improve soil quality to sustain increases in productivity, stability, and environmental services through greater understanding of processes that govern soil quality and trends in soil quality in intensive systems), and 7 (To optimize productivity at high input use (e.g. labor, nutrients, pest control practices, water, seed, and feed) through understanding and managing spatial and temporal variation).

Impact pathways:

The 5 major outputs outlined above in the rationale section articulate the logical relationship of activities within the project logframe. Output 1 (*Biophysical and socioeconomic processes understood, principles and concepts developed for protecting and improving the health and fertility of soils*) encompasses our research developing principles and concepts that transcend the classical boundaries of the biophysical sciences through integration with economics, sociology and anthropology. Local and scientific knowledge interact to develop integrated "hybrid" knowledge for soil fertility management, improved food security, and environmental protection. The intended users of the ISFM principles and concepts are CGIAR, ARIs, researchers from NARS and local universities, NGOs, farmers, and regional consortia. These intended users are applying the principles, concepts and methods to improve technologies and system understanding. The final impacts of this output are resilient production systems and sustainable agriculture based on improved soil health and fertility.

The process and integrated knowledge generated under Output 1 activities is therefore applied as sustainable soil fertility and land management practices, shaped by and responding to the socio-cultural and economic environment. Research activities from Output 2 (*Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical and socioeconomic processes*) address the social, economic, and gendered dynamics of local knowledge generation and exchange, the nature of the interface between research-extension, local community institutions/social networks, and evaluate the economic and environmental impacts of current or proposed practices. These activities provide general principles and methodologies for TSBF-CIAT and partners to enhance farmers' capacity for applying best principles for sustainable soil, water and land management practices.

At the center of the research-outcome-impact chain, Output 3 (*Partnerships and tools developed and capacity enhanced of all stakeholders for improving the health and fertility of soils*) addresses the building of human and social capital of all TSBF-CIAT stakeholders for effective research and sustainable management of tropical soils. This is particularly necessary since the managing soil fertility

for improved livelihoods requires an approach that integrates technical, social, economic and policy issues at multiple scales. To overcome this complexity, research and extension staff need the capacity to generate and share information that will be relevant to other stakeholders working at different scales (i.e., policy makers, farmers).

Output 4 (*Improved rural livelihoods through sustainable, profitable, diverse and intensive agricultural production systems*) represents the application of human and social capital and sound, socio-culturally and economically relevant biophysical principles for ISFM. The challenge of intensification and diversification of smallholder agricultural production is that meeting the food and income needs of the poor cannot occur without investment in natural resource management, especially soil fertility. Investment in improving soil fertility is not constrained by a lack of technical solutions *per se* but is more linked to lack of access to information for improved decision making and analyzing trade-offs, inputs and profitable markets.

The highest scale for our research-for-development activities is found within Output 5 (*Options for sustainable land management (SLM) practices for social profitability developed, with special emphasis on reversing land degradation*). These activities are dedicated to applying the findings of all the previous outputs for restoring degraded agricultural lands to economic and ecological productivity, enhancing ecosystem health and improving livelihoods by generating technology, institutional, and policy innovations. Since soils play a central role for the provision of ecosystem services (e.g. regulation of water quality and quantity, carbon storage and control of net fluxes of greenhouse gases to the atmosphere), appropriate soil management at the landscape level should result in enhanced provision of environmental services.

The key assumptions for these 5 outputs are: security and political stability does not restrict access to target sites and continuation of on-going activities; poverty reduction strategies remain central to human development support and funding; TSBF-CIAT stakeholders remain engaged with TSBF-CIAT strategic priorities and/or TSBF-CIAT management continues to adapt and innovate in response to changing priorities; funding for research on globally-important issues continues; and linkages maintained among research and development organizations. The expected beneficiaries, target ecosystems and end users are principally small-scale crop-livestock farmers and extension workers, NGOs and NARES in tropical agroecosystems of Sub-Saharan Africa, Latin America and South-east Asia. The target ecoregions are East and Central African highlands (Kenya, Uganda, Ethiopia, Tanzania, Rwanda, DR Congo); Southern African savannas (Zimbabwe, Malawi, Mozambique, Zambia); West African region (Burkina Faso, Niger, Cote d'Ivoire, Nigeria, Benin, Togo, Mali, Senegal, Ghana); Central American hillsides (Honduras, Nicaragua); Andean hillsides (Colombia, Ecuador, Peru, Bolivia); Tropical savannas of south America (Colombia, Venezuela); and Amazon rainforest (Brazil, Colombia, Peru).

International Public Goods (IPG):

The IPG of the PE-2 project include:

- Improved knowledge on soil processes;
- Global inventory of below-ground biodiversity;
- Improved knowledge on nutrient and other resource flows;
- Improved knowledge on how different stakeholders use and manage landscapes;
- Tools and indicators to assess soil quality;
- Improved approaches and practices for managing soil, water and land resources;
- Innovative diversification options within farms;
- Decision support tools and models to analyze trade-offs among food productivity, ecosystem services and land conservation;

- ∉ Methods and tools for promoting effective collective action for improved soil fertility management and improved livelihoods;
- ∉ Novel forms of institutional innovations and policy options to reduce land degradation and to restore degraded lands.

The Institute's comparative advantage is in conducting IPG research on ISFM in farming systems where soil degradation undermines local livelihoods and market opportunities. However, while TSBF-CIAT will focus primarily on strategic research, it is also ready to support technology dissemination and development activities with partners via regional networks and global projects. TSBF-CIAT will continue research on below-ground biodiversity as a means of beneficially managing soil biology, through the GEF-UNEP funded global project on below-ground biodiversity (BGBD) which has successfully completed its Phase I and is about to start its Phase II activities. Much of the applied research and dissemination of findings, as well as NARSs capacity building, will be done via the Institute's regional partner networks/consortia — the African Network for Soil Biology and Fertility (AfNet), the Latin American Consortium on Integrated Soil Management (known by its Spanish acronym, MIS), and the Consortium for Sustainable Development of the Andean Region (CONDESAN). TSBF-CIAT also collaborates with the South Asian Regional Network (SARNet) on soil fertility research in that region.

Partners:

NARES: These are important local partners that contribute staff time and operational resources to all 5 outputs of the project. The staff time of NARES partners is indicated for each country. East and Central African highlands (Kenya-10, Uganda-4, Ethiopia-1, Tanzania-1, Rwanda-5, DR Congo-5); Southern African savannas (Zimbabwe-3, Malawi-1 Mozambique-1, Zambia-1); West African region (Burkina Faso-1, Niger-3, Cote d'Ivoire-2, Nigeria-2, Benin-1, Togo-1, Mali-1, Senegal-1, Ghana-2; Central American hillsides (Honduras-4, Nicaragua-3); Andean hillsides (Colombia-2, Ecuador-1, Peru-1; Bolivia-1); Tropical savannas of south America (Colombia-3, Venezuela-1); Amazon rainforest (Brazil-3, Colombia-1, Peru-1).

ARIs: These are important international partners that contribute to mostly to strategic research in output 1 on biophysical and socioeconomic processes and output 2 on natural resource management strategies. These include CIMMYT-1, ILRI-1, CIP-1, IFDC-1 ICRAF-2, IITA-2, ICRISAT-2, IRD (France-1), CIRAD (France-2), ETHZ (Switzerland-1), and JIRCAS (Japan-2).

Universities: These are local and international partners that participate mostly in co-supervision of students that work on ISFM related aspects. Nacional (Colombia-6), UNA (Nicaragua-5), UNA and EAP Zamorano (Honduras-6), Uberlandia (Brasil-1), University of Nairobi (Kenya-2), Maseno University (Kenya-1), Makerere University (Uganda-2), Kenyatta University (Kenya-2), Zimbabwe (Zimbabwe-2), Sokoine (Tanzania-1), Universidade Federal de Lavras (Brazil-1), Universidade Regionale de Lavras-FURB (Brasil-1), INPA (Brasil-1), UFAM (Brasil-1), Universidade De Brasilia (Brasil-1), Jawaharlal Nehru University (India-1), University of Agricultural Sciences (India-1), Kumaon University (India-1), Sambalpur University (India-1), Universitas Lampung (Indonesia-1), Brawijaya University (Indonesia-1), Gadjah Mada University (Indonesia-1), Bogor Agricultural University (Indonesia-1), Université de Cocody (Cote d'Ivoire-1), Universite D'Adobo-Adame (Cote d'Ivoire-1), Universidade Veracruziana (Mexico-1), Instituto Polytecnico (Mexico-1, Leuven (Belgium-2), Paris (France-1), Bayreuth and Hohenheim (Germany-3), SLU (Sweden-3), NAU (Norway-1), Cornell (USA-2), Wisconsin-Madison (USA-1), U.C. Davis (USA-1), Ohio State (USA-1), Colorado State University (USA-1), East Anglia (UK-1), Queen Mary University (USA-1), Michigan State University (USA-1), ITC (The Netherlands-1) University of Exeter (UK-1), and Wageningen University and Research Centre (Netherlands-3).KU-Leuven University (4).

Regional Consortia: These partners play a key role in building capacity in the regions for ISFM research and also for dissemination of tools and technologies to promote ISFM. These include AFNET for Sub-Saharan Africa, African Highlands Initiative for African highlands, MIS for Central America, and CONDESAN for the Andean region of South America.

NGOs: These partners play a key role in dissemination of tools and technologies for ISFM in the regions. These include CARE-Kenya, World Vision, CIPASLA and CIPAV.

In addition to the above partners, PE-2 project also participates with Systemwide Programs (AHI, PRGA) and Challenge Programs (Water and Food CP, SSA-CP).

Project Funding:

Budgeting 2005-2009

Year	**2005 (actual)**	**2006 (actual)**	**2007 (proposal)**	**2008 (plan)**	**2009 (plan)**
US Dollars (millions)	6.405	4.790	6.012	5.710	5.538

CIAT PROJECT PE-2: INTEGRATED SOIL FERTILITY MANAGEMENT IN THE TROPICS (2007-2009)

Targets	Outputs	Intended User	Outcome	Impact
OUTPUT 1	Biophysical and socioeconomic processes understood, principles, concepts and methods developed for protecting and improving the health and fertility of soils	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Principles, concepts and methods inform technology and system development	Improved soil health and fertility contribute to resilient production systems and sustainable agriculture
Output Targets 2007	At least three indicators of soil quality at plot and farm scales in acid soil savannas identified	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Partners begin validating indicators of soil health and fertility	
	Land use intensity impact on BGBD evaluated in seven tropical countries participating in the BGBD project	Scientists participating in the BGBD project, ARIs, CGIAR, researchers from NARS and local universities, and farmers	Links between BGBD and land use management established and used as basis for developing sustainability in tropical farming systems	
	At least two indicators of soil quality used for farmer's decision making in hillsides agroecosystem	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Partners incorporate farmer decision making in new proposals and on–going activities	
Output Targets 2008	Practical methods for rapid assessment and monitoring of soil resource base status developed	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Partners are using the methods with farmers	
	The social, gender, and livelihood constraints and priorities affecting the sustainable use of soils have been identified, characterized, and documented through case studies using innovative methods	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Partners are working to overcome the identified constraints with new proposals and on-going research	

Targets	Outputs	Intended User	Outcome	Impact
Output Targets 2009	Decision tools for soil biota and nutrient management developed and disseminated to stakeholders	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Partners involved in research for development are using the decision tools	
	Knowledge on relationships between soil fertility status and the nutritional quality of bio-fortified crops is used by development partners to target production of these crops	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Stakeholders in research for development focus on food quality in addition to production	
	Sufficient knowledge on mechanisms driving tolerance to drought and low soil P is available to guide breeding efforts	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Breeders involve soil scientists in the breeding program	
OUTPUT 2	Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical, socio-cultural and economic processes	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Technologies, systems and soil management strategies adopted and adapted through partnerships	Adapted technologies contribute to food security, income generation and health of farmers
Output Targets 2007	Banana, bean and cassava-based systems, with the relation between pest, diseases and ISFM as entry point, including novel cropping sequences, tested and adapted to farmer circumstances in Africa	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Banana, bean and cassava-based systems and soil management strategies adopted and adapted through partnerships	
	Benefits of agropastoral systems on crop productivity and soil quality quantified in acid soil savannas	CGIAR, ARI, researchers from NARS and local universities	Agropastoral systems and soil management strategies adopted and adapted through partnerships	

Targets	Outputs	Intended User	Outcome	Impact
Output Targets 2008	Communities in at least three countries demonstrate and test direct or indirect management options that enhance locally important ecosystem services using BGBD	BGBD network, CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers and global conservation organizations	Researchers, farmers, land users and policy makers and global conservation organizations increase their awareness of the benefits of conserving and managing BGBD	
	Quesungual and other related agroforestry systems, with soil and water conservation as entry point, including crop diversification strategies, tested and adapted to farmer circumstances in Central America	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Quesungual system and soil management strategies adopted and adapted through partnerships	
Output Targets 2009	Local baselines and interviews show that farmers' understanding of soil processes is demonstrably enhanced within community-based experimentation in at least 5 benchmark sites	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Scientists blend local and new scientific knowledge in the experimental design	
	The potential for occurrence of positive interactions between organic and mineral inputs is evaluated for the most common cropping systems in each mandate area.	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Stakeholders appreciate the complementary role of both inorganic and organic inputs and use them judiciously	
	Throughout the Institute project life, new questions generated in the evaluation efforts of the different target outputs are addressed and fed back to these evaluation activities	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	PM&E is institutionalized and used by all project partners	

Targets	Outputs	Intended User	Outcome	Impact
OUTPUT 3	Partnerships and tools developed and capacity enhanced of all stakeholders for improving the health and fertility of soils	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Strengthened and expanded partnerships for ISFM facilitate south-south exchange of knowledge and technologies	Improved institutional capacity in aspects related to ISFM and SLM in the tropics contribute to agricultural and environmental sustainability
Output Targets 2007	Strategy for building capacity for SLM is developed with partners	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	TSBF-CIAT scientists and partners lead globally-funded research on at least three topics of key relevance to the international community (as identified in GEF, MDG, MEA, CGIAR mission and goal statements)	
	At least three capacity building courses on ISFM held by AfNet and MIS	AfNet, MIS	Partners incorporating new knowledge and skills in new proposals and on-going research efforts	
	Books, web content and papers produced by partners in BGBD project both north and south in seven tropical countries	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Partners incorporating new knowledge and skills in new proposals and on-going research efforts	
Output Targets 2008	Farmer-to farmer knowledge sharing and extension through organized field trips and research activities result practices in at least two sites	Researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Farmers realize benefits of knowledge sharing	

Targets	Outputs	Intended User	Outcome	Impact
	Web content in the BGBD website enhanced to contain data and information on BGBD taxonomy and species identification	Researchers, CGIAR, ARI, local universities	Increased number of biodiversity scientists use the website for proper identification and classification of soil biota to species level	
Output Targets 2009	Profitable land use innovations scaled out beyond pilot learning sites through strategic alliances and partnerships, and application of alternative dissemination approaches.	Researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Partners incorporating new knowledge and skills in new proposals and on-going research efforts	
	At least three capacity building courses on ISFM held by AfNet and MIS	Researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Partners use the T shape approach that enhance efficiency in R4D	
	Strategies for institutionalization of participatory NRM approaches and methodologies established	Researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	New institutional arrangement catalyse multidisciplinary work and enhance scaling up of technologies and best practices	
OUTPUT 4	Improved rural livelihoods through sustainable, profitable, diverse and intensive agricultural production systems	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Partners promoting resilient production systems with multiple benefits (food security, income, human health and environmental services)	Improved resilience of production systems contribute to food security, income generation and health of farmers
Output Targets 2007	Crop-livestock systems with triple benefits tested and adapted to farmer circumstances in hillsides	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Farmers are testing and adapting improved production systems in at least 15 sites across five countries	

Targets	Outputs	Intended User	Outcome	Impact
	Strategies of BGBD management for crop yield enhancement, disease control, and other environmental services demonstrated in seven tropical countries participating in the BGBD project	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Farmers and governments adopting BGBD technologies in crop production and ecosystems services	
Output Targets 2008	Improved production systems having multiple benefits of food security, income, human health and environmental services identified	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Market-led hypothesis is incorporated in systems experimentation; Different partners linking food security, environmental sustainability and income generation to health	
Output Targets 2009	Validated intensive and profitable systems are being demonstrated, promoted by partners and adopted by farmers in 10 countries	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Increased sustainable productivity and profitability of major cropping systems	
	The contribution of multiple stress adapted germplasm in driving overall system resilience is understood for the conditions occurring in all mandate areas	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Farmers pay more attention to the sustainability of their farming system in addition to productivity	
	Products of the trade-off analysis are guiding the introduction and evaluation of alternative NRM options, better suited to the farmer production objectives and the environment of the actions sites	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Farmers use results of trade off analysis to make appropriate choice	

Targets	Outputs	Intended User	Outcome	Impact
OUTPUT 5	Options for sustainable land management (SLM) for social profitability developed, with special emphasis on reversing land degradation	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Principles of sustainable land management integrated in country policies and programs	Reversing land degradation contribute to global SLM priorities and goals
Output Targets 2007	Decision tools (GEOSOIL; Decision Tree) available for land use planning and targeting production systems in acid soil savannas	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers	Local organizations using the decision tools for land use planning	
	Biophysical, social and policy niches in the landscape for targeting SLM technologies and enhanced ecosystem services identified and prioritized	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers	Methods of SLM are incorporated in the design of landscape research	
Output Targets 2008	Methods developed for socio-cultural and economic valuation of ecosystem services developed and applied for trade-off and policy analysis in at least in 1 humid and 1 sub-humid agroecological zones	CGIAR, ARI, researchers from NARS and local universities, BGBD network, NGOs, farmers, regional consortia, policy makers	Methods of SLM are incorporated in the design and evaluation of landscape research	
	In at least four of the countries participating in the BGBD project, policy stimulated to include matters related to BGBD management, and sustainable utilization.	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers	Policy issues related to BGBD acquisition, exchange, intellectual property rights (IPR), benefits sharing, etc. included in local, national and regional government policies	

Targets	Outputs	Intended User	Outcome	Impact
Output Targets 2009	30% of partner farmers in pilot sites used SLM options that arrested resource degradation and increased productivity in comparison with non-treated farms	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers	Increased productivity and conservation of degraded landscape	
	75% of stakeholders in target areas have an improved capacity for collective action and local policy negotiation and implementation of integrated land use practices using integrated agricultural research for development	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers	Improved knowledge sharing and exchange to empower stakeholder to innovate with respect to technologies and best land conservation practices	
	The benefits of community-based watershed management innovations quantified and disaggregated by wealth and gender	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers	Increased investment in beneficial conservation	

3. RESEARCH HIGHLIGHTS 2006

Output 1: Biophysical and socioeconomic processes understood, principles, concepts and methods developed for protecting and improving the health and fertility of soils

Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe: An improved understanding of soil fertility variability and farmers' resource use strategies is required for targeting soil fertility improving technologies to different niches within farms. We measured the variability of soil fertility with distance from homesteads on smallholder farms of different socio-economic groups on two soil types, a granite sand and a red clay, in Murewa, northeast Zimbabwe. Soil organic matter, available P and CEC decreased with distance from homestead on most farms. Available P was most responsive to management, irrespective of soil type, as it was more concentrated on the plots closest to homesteads on wealthy farms (8 to 13 mg kg^{-1}), compared with plots further from homesteads and all plots on poor farms (2-6 mg kg^{-1}). There was a large gap in amounts of mineral fertilizers used by the wealthiest farmers (>100 kg N and 15 kg P per farm) and the poorest farmers (<20 kg N and <10 kg P per farm). The wealthy farmers who owned cattle also used large amounts of manure, which provided at least 90 kg N and 25 kg P per farm. The poor farmers used little or no organic sources of nutrients. The wealthiest farmers distributed mineral fertilizers evenly across their farms, but preferentially targeted manure to the plots closest to the homesteads, which received about 70 kg N and 25 kg P per plot from manure compared with 20 kg N and 8 kg P per plot on the mid-fields, and 10 kg N and 2 kg P per plot on the outfields. All the farmers invariably applied nutrients to maize but little to groundnut. Maize grain yields were largest on the homefields on the wealthy farms (2.7 to 5.0 Mg ha^{-1}), but poor across all fields on the poor farms (0.3 to 1.9 t ha^{-1}). Groundnut grain yields showed little difference between farms and plots. N and P partial balances were largest on the wealthy farms, although these fluctuated from season to season (–20 to +80 kg N per farm and 15 to 30 kg P per farm). The partial balances on the wealthy farms were largest on the homefield (20 to 30 kg N and 13 kg P per plot), but decreased to 10 to 20 N and 6 to 9 kg P per plot in midfields and –7 to +10 kg N and –1 to +1 kg P per plot in the outfields. N and P balances differed little across plots on the poor farms (–5 to +5 kg per plot) due to limited nutrients applied and small off-take from small harvests. Full N and P balances were negative for most farms and plots due to large nutrient losses estimated for soil erosion (12 to 30 kg N ha^{-1} and 6 to 15 kg P ha^{-1}), leaching (21 to 26 kg N ha^{-1}) and denitrification (3 to 16 kg N ha^{-1}). This study highlights the need to consider soil fertility gradients and the nutrient management patterns creating them when designing options to improve resource use efficiency on smallholder farms.

Exploration of Integrated Soil Fertility Management for Banana Production and Marketing in Uganda and Kenya - Arbuscular Mycorrhizal Fungi help establishment and production of tissue culture banana: Although once a highly sustainable crop, banana has seen precipitous yield declines in its traditional growing areas in Uganda and Kenya due to a number of pests and diseases including weevils, nematodes, fusarium wilt, black sigatoka and more recently banana streak virus. Yields, however, continue to decrease even when pressure to diseases and pests is alleviated. Declining soil fertility has also been cited as a contributory factor. According to the Ministry of Agriculture, Ugandan farmers attain approximately 17 % of the potential yield from banana i.e., 5.9 t ha^{-1} compared with on-station levels of up to 35 t ha^{-1} Soil fertility has been handled rather empirically in banana based cropping systems, leading to recommendations with little opportunities to be extrapolated to different situations. To tackle the soil- and pest/disease-related decline in banana production, we aim: (i) to improve the quality and quantity of marketable banana products by developing and disseminating low-cost integrated soil fertility management practices to support the intensification and commercialization of sustainable production systems and (ii) to increase the establishment and production of tissue culture banana by exploring better utilization of AMF. *Tissue culture* (TC) plantlets offer an excellent means of providing pest and disease-free planting material to farmers. Preliminary evidence shows that inoculation with

proper *arbuscular-mycorrhizal fungi* (AMF) enhances the early survival of tissue culture bananas. Other preliminary evidence also shows that enhanced AMF infection can have negative impacts on the proliferation of certain soil-borne pests and diseases (e.g., nematode infection). Obviously, the impact of inoculation needs to be visible at the farm level (e.g., through enhanced survival of TC plantlets). Inoculation with AMF shows considerable potential to enhance the growth of tissue-culture bananas, although observations after transplanting the plants under field conditions and observing their growth and production under field conditions is required before firm conclusions can be drawn. Association with banana showed bananas to be highly dependant on AMF association although they exhibited preference for AMF species, hence the importance of collecting AMF germplasm from banana plantations to screen for effectiveness on plant growth, nutrient uptake and control of root and soil borne pests and pathogens. Fungi isolated from existing banana plantations could further outperform the strains used in the current trial, which is one of the follow-up activities currently being implemented. Efforts will be made to continue looking for better AMF strains from existing banana plantations and to quantify the medium-to-long term effects of this better initial growth under field conditions.

Building consensus to influence soil processes at landscape scale: A participatory approach and a methodological guide were developed to identify and classify local indicators of soil quality and relate them to technical soil parameters, and thus develop a common language between farmers, extension workers and scientists. This methodological guide was initially developed and used in Latin America and the Caribbean-LAC (Honduras, Nicaragua, Colombia, Peru, Venezuela, Dominican Republic), and was later improved during adaptation and use in eastern African (Uganda, Tanzania, Kenya, Ethiopia) through a South-South exchange of expertise and experiences. The aim of the methodological guide is to constitute an initial step in the empowerment of local communities to develop a local soil quality monitoring and decision-making system for better management of soil resources. This approach uses consensus building to develop practical solutions to soil management constraints, as well as to monitor the impact of soil management strategies implemented to address these constraints. Development of local capacities for consensus building is strongly encouraged because it constitutes a critical step prior to collective action by farming communities resulting in the adoption of integrated soil fertility management strategies at the farm and landscape scales.

Biological nitrification inhibition is a widespread phenomenon among crops and forages: Collaborative research between JIRCAS, Japan and CIAT has shown that biological nitrification inhibition (BNI) is widespread among plants with significant inter- and intra-specific variability and suggested that this genetically controlled BNI function could have the potential to be managed and/or introduced into pasture grasses/crops that do not exhibit the phenomenon *via* genetic improvement approaches that combine high productivity with the capacity to regulate soil nitrification. We screened 43 accessions of *Brachiaria humidicola* for specific and total biological nitrification inhibitory (BNI) activity and quantified genetic diversity in BNI and identified contrasting accessions with very high (CIAT 26573) and low BNI activity (CIAT 16880). Field studies after four cycles of analyses for BNI activity indicated that nitrification rates were lower with the two accessions of *Brachiaria humidicola* than the accession of *Panicum maximum*. A highly sensitive soil incubation method to estimate nitrite formation was tested and adapted to detect even small differences in nitrification rates among the grasses.

Output 2: Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical and socioeconomic processes

Within-farm soil fertility gradients affect response of maize to fertilizer application in western Kenya: Different fields within a farm have been observed to have different soil fertility status and this may affect the response of a maize crop to applied N, P, and K fertilizer. A limiting nutrient trial was

carried out at six farms each, in three districts of Western Kenya. In each of the farms, the following treatments were laid out in three fields with different soil fertility status at different distances from the homestead (close, mid-distance, remote fields): no inputs, application of NPK, NP, NK, or PK fertilizer (urea, triple super phosphate, KCl) to maize. Total soil N decreased at all sites with distance to the homestead (from 1.30 to 1.06 g kg^{-1}), as did Olsen-P (from 10.5 to 2.3 mg kg^{-1}). Grain yields in the no-input control plots reflected this decrease in soil fertility status with distance to the homestead (from 2.59 to 1.59 Mg ha^{-1}). In the NPK treatments, however, this difference between field types disappeared (from 3.43 to 3.98 Mg ha^{-1}), indicating that N and P are the major limiting nutrients in the target areas. Response to applied N was related to the soil total N content in Aludeka and Shinyalu, but not in Emuhaya, probably related to the high use of partially decomposed organic inputs with limited N availability. Consequently, response to applied N decreased with distance to the homestead in Aludeka (from 0.95 kg kg^{-1} relative yield to 0.55 kg kg^{-1}) and Shinyalu (from 0.76 kg kg^{-1} to 0.47 kg kg^{-1}), but not in Emuhaia (from 0.75 kg kg^{-1} to 0.68 kg kg^{-1}). Response to applied P was related to the soil Olsen-P content at all sites. While for farms with a relatively high Olsen-P gradient, response to applied P decreased with distance to the homestead (from 0.99 kg kg^{-1} to 0.68 kg kg^{-1}), large variability in Olsen-P gradients across field types among farms within a specific site often masked clear differences in response to P between field types for a specific site. Clear scope for field-specific fertilizer recommendations exists, provided these are based on local soil knowledge and diagnosis. Scenario analysis, using farm-scale modelling tools, could assist in determining optimum allocation strategies of scarcely available fertilizer for maximum fertilizer use efficiency.

Advances in defining the key principles behind the social acceptance and biophysical resilience of Quesungual Slash and Mulch Agroforestry System (QSMAS): The knowledge generated by the QSMAS project funded Water and Food CP is confirming that it is possible to achieve food security in drought-prone areas of the sub-humid tropics without compromising soil, water and vegetation resource quality. Collaborative research between TSBF-LAC and MIS consortium in Central America for the past 2 years contributed to the following progress: (i) QSMAS is a production system inserted into the landscape to improve livelihoods while conserving the natural resource base; (ii) local biodiversity is favored through the conservation of about 14 species (from 12 families) of trees and shrubs; (iii) soil losses due to erosion are dramatically reduced due to a combined effect of permanent soil cover and presence of stones in soil leading to improved water productivity and quality; (iv) pools of soil nutrients (N and P) maintained or even increased while soil biodiversity and biological activity is enhanced and these improvements in resource quality were related to the spatial distribution of trees and organic resources; and (v) the system is an important source of firewood for domestic consumption and has no significant negative effects on greenhouse gas emissions. Validation of QSMAS in Nicaragua had advanced more than expected, with participating farmers extending the system to other regions. Capacity of local farmers and technicians is being enhanced through field days and graduate and undergraduate students from the region through degree training.

Output 3: Partnerships and tools developed and capacity enhanced of all stakeholders for improving the health and fertility of soils

Strengthening 'folk ecology': community-based learning for integrated soil fertility management, western Kenya: Farmers and researchers in western Kenya have used community-based learning approaches to jointly develop a 'dynamic expertise' of integrated soil fertility management (ISFM). This transformative learning approach builds on farmers' "folk ecology" and outsiders' knowledge, taking action research on natural resource management beyond methods that are descriptive (ethnopedology) or curriculum driven (farmer field schools). The paper presents insights from a project's experience of applying the strengthening "folk ecology" approach in western Kenya, with emphasis on the community-based learning process, collective and individual experimentation, the power dynamics of farmer research groups, and learning from the farmer–researcher interface. Farmer groups have been empowered by this

approach but diversification into non-soil activities highlights the limitations of experimentation and the challenges of scaling up participatory action research.

The African Network for Soil Biology and Fertility (AfNet): The African Network for Soil Biology and Fertility (AfNet) continues to be a cornerstone of soil fertility research in Africa. This has been through the support of research activities in several sites scattered all over the East, West, Central and Southern Africa. In 2006 several trials were continued and these continue to provide vital information on the performance of the various soil and water management technologies being developed and tried out by researchers and farmers. In its effort to build capacity of researchers in the region, AfNet organized two training workshops: Gender mainstreaming and participatory research, monitoring and evaluation which were attended by several AfNet members. These training courses have improved the 'T-shaped' skills of the scientists making them able to address the complex issues affecting resource allocation and natural resource management at farm level. AfNet supported the organization of the Soil Science Society of East Africa (SSSEA) conference and also sponsored several members to attend workshops/conferences where they resented their research findings. AfNet continues to support student training at both MSc and PhD levels. During 2006, 22 students were supported and/or supervised in their studies. Several papers were also published by AfNet staff in refereed journals. The year 2006 saw the publication by Nutrient Cycling in Agroecosystems Journal of the AfNet Symposium Special Issue titled: *Advances in integrated soil fertility management in sub-Saharan Africa: Challenges and Opportunities*. The Special issue contains 19 papers out of the 104 papers presented at the AfNet Yaoundé Symposium. Through AfNet, *The Comminutor*, Newsletter of the TSBF Institute of CIAT Vol. 10: 1 June 2006 was published. The report presents the major research highlights and activities of AfNet during the year 2006.

Application of NuMaSS recommended rates resulted in substantial savings in fertilizer use by farmers: Completion of a network of N fertilization trials in Honduras and Nicaragua provided soil and crop N coefficients for the six most common maize varieties grown in the region. Along with the interim release of the Data Base Editor Module for NuMaSS, these coefficients are enabling users (MIS partners, farmers and NGO`s groups) to customize the software's database and make site- and varietal-specific fertilizer N recommendations within their regional domains. Six NGOs working with FAO in subsistence farming communities of Honduras were trained in NuMaSS and are using the customized database to develop N recommendations for their demonstration trials with farmers. Results are showing that application of NuMaSS recommended rates resulted in substantial savings in fertilizer use by farmers. NARS from both countries (INTA-Nicaragua and DICTA-Honduras) agreed to include NuMaSS in their operational plan for 2007 and lead further validation of the system

Output 4: Improved rural livelihoods through sustainable, profitable, diverse and intensive agricultural production systems

Profitability of agro-forestry based soil fertility management technologies: the case of small holder food production in Western Kenya: Persistent food insecurity accompanied by low and declining farm household incomes are a common feature of many small holder maize and bean producers in western Kenya. This has been largely attributed to soil nutrient depletion, among other factors. One way of addressing soil fertility problems in many maize-based cropping systems is the use of agro-forestry based technologies. We carried out a survey in western Kenya (Vihiga and Siaya districts) aimed at analyzing the financial and social profitability of use of agroforestry based (improved tree fallows) and other soil fertility management technologies among smallholder farmers. The Policy Analysis Matrix (PAM) was used to determine the financial and social profitability of different production systems, which were categorized on the basis of the technology used to address soil fertility. Farm budgets were first prepared and in turn used to construct the PAMs for six production systems namely: maize–bean intercrop without any soil fertility management inputs; maize–bean intercrop with chemical fertilizers only; maize–bean intercrop with a combination of chemical fertilizers and improved fallows; maize–bean intercrop with

improved fallows only; maize–bean intercrop with a combination of improved fallows and rock phosphate; and maize–bean intercrop with Farm Yard Manure (FYM) only. Results revealed that use of chemical fertilizers with improved fallows was the most profitable technology and thus the study recommended that farmers be encouraged to intensify the use of chemical fertilizers. To make chemical fertilizers more accessible to farmers, the study also recommended that good linkages be made between farmers and micro credit institutions so that small scale farmers are not actually biased against due to lack of collateral when credit is being advanced to clients.

Output 5: Options for sustainable land management (SLM) practices for social profitability developed, with special emphasis on reversing land degradation

Socio-ecological niche: a conceptual framework for integration of legumes in smallholder farming systems: There are numerous examples of technologies with great potential that have not been accepted by smallholder farmers. Quite often, these technologies do not fit well into smallholder systems due to the inherent high level of heterogeneity of these systems. For example, despite their great potential, the adoption of legumes by smallholder farmers in many parts of sub-Saharan Africa has remained poor. A wide range of biophysical (e.g. climate, soil fertility, etc.) and socio-economic variables (e.g. preferences, prices, production objectives etc.) influence the use of legumes in smallholder systems. While some of these variables constrain the adoption of some legumes, others offer opportunities for beneficial use of other legumes in the same system. Therefore, widespread adoption of legumes in smallholder systems can only be achieved if all of the major biophysical and socio-economic constraints are simultaneously identified and addressed. The 'socio-ecological niche' concept proposed in this paper provides the framework through which this might be achieved. The socio-ecological niche, in any given region of agricultural activity, is created by the convergence of agro-ecological, socio-cultural, economic and ecological factors, to describe a multidimensional environment for which compatible technologies can be predicted. The socio-ecological niche concept can be applied in many different contexts in technology development. However, this paper discusses its use with respect to the development of legume technologies. Two case studies are presented to illustrate the concept and to demonstrate its practical significance. The concept is being used in on-going research on legumes in smallholder farming systems in western Kenya.

Assessment of the hydrological services and socioeconomic effects of Payment for Environmental Services (PES) schemes in the Andes: During the last decade, schemes of PES are considered as mechanisms that could promote SLM (sustainable land management) without depleting the socioeconomic conditions of inhabitants of the Andean watersheds. However, there are only few cases where proper quantification and valuation of those impacts are assessed. This is the case of the Pimampiro PES scheme in Ecuador that was created five years ago to facilitate payments from the urban water users to the households located in the Palahurco River micro-watershed. By means of hydrological modelling and trade off analysis these effects were measured and valued. Thus, it was found that guarantying forest cover with the payments avoids actual increments of the sediment yield, since if it is replaced by the current agricultural systems the sediments will be increased by about three times. From the socioeconomic standpoint, although the current payment amounts are relatively low, they do represent an economic incentive. This is explained by the fact that the opportunity cost of conserving these areas is practically equal to what they receive through the conservation payments. In terms of additionality, there is a potential to reduce current sediment yield. If current agricultural areas are replaced by forests, the current sediments could be lowered by about 68%. However, this change in land use will require an increment in the payment amounts as the opportunity costs will be higher. This methodology is also applied to other Andean watersheds where PES schemes are at the design stage. This will permit to target spatial areas were maximum impact on environmental services can be reached and will enable to calculate the amount of money that should be paid to the service providers.

Using carbon trading for promoting SLM alternatives in marginal lands: A carbon sequestration project for the tropical savannas of northern Colombia was designed and negotiated with the Biocarbon Fund. The proposed carbon sequestration components are silvopsatoral systems and commercial forest plantations in 2600 ha of low productive lands. In order to develop concrete plans for the carbon emission reductions (CERs) with the Biocarbon Fund, eligible areas were identified according to the UNFCCC (United Nations Framework Convention on Climate Change) conditions, the baseline from the socioeconomic and carbon stock perspective was characterized and the ex ante net anthropogenic GHG (greenhouse gas) removal by the proposed systems were calculated. In general the IRR (internal rate of return) calculated for the project is around 20% and when the social benefits caused by income and employment are included, that is, all benefits not collected directly by the producers but received by society; the project IRR is around 30%. The ex ante calculation of GHG removals resulted in 246992 CO2-e to 2017 and 1015839 CO2-e to 2037. The project will be executed in 2007 by the Colombian National Agricultural Research Organization (CORPOICA), the Environmental Corporation of the Sinu and San Jorge Rivers (CVS) and CIAT.

4. PROJECT OUTCOME

Developed dual-purpose soybean value chain and increased income of smallholder farm families and other rural entrepreneurs in East Africa

TSBF-CIAT and its partners contributed to improved rural livelihoods in East Africa (Kenya, Uganda, Tanzania) through enhanced income, improved health, and more sustainable agriculture by increasing the land cropped with dual-purpose soybean and fostering links between production and demand. This outcome resulted from the activities of Output 4 of PE-2 Project (TSBF Institute) on "Improved rural livelihoods through profitable, diverse and intensive agricultural production systems" of CIAT-MTP 2004-2006. The number of farmer groups (15–130 individual members each) growing soybean has increased from three to 16 in three districts in western Kenya in 2005 in less than two cropping seasons. The corresponding area planted to soybean by the groups increased from 4.1 ha to 16.3 ha in *Migori* district, 1.6 ha to 6.2 ha in *Butere-Mumias* district. Results in 2006 show that over 300 networks of farmers' groups and 4,000 individual farmers from more than 10 districts are presently participating in soybean promotion in Kenya; up from 9 farmers' groups and 180 individual farmers at project inception. The area cultivated to soybean has increased more than 10-fold, with yields improving from 0.6t/ha to about 1.5 t/ha. Network of farmers' groups is already supplying large-scale feed/food processing companies with increasing quantities of top quality soybeans with market desired traits. Farmers' bulking of produce is generating tangible results with some farmers' groups already delivering grains with market-preferred traits to processing companies at agreed market clearing prices. Many poor farmers testified to increased ability to pay children's school fees and purchase of inputs (mineral fertilizers, etc.). Some farmers are beginning to remove sugarcane (so-called "cash crop" that no longer brings cash due to market collapse caused by globalization) from their lands, replacing them with soybean (Reuben Omondi et al. personal communication/ observation).