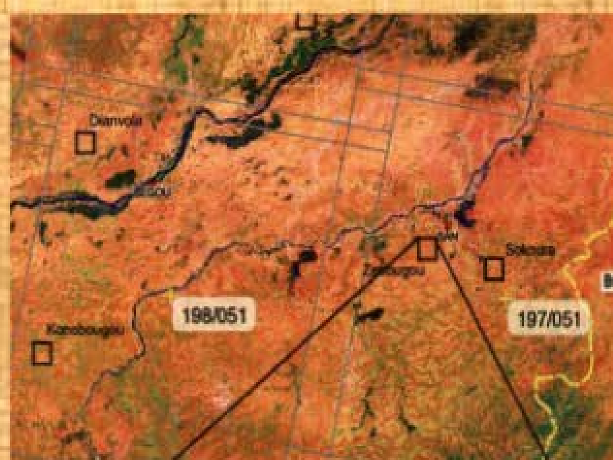
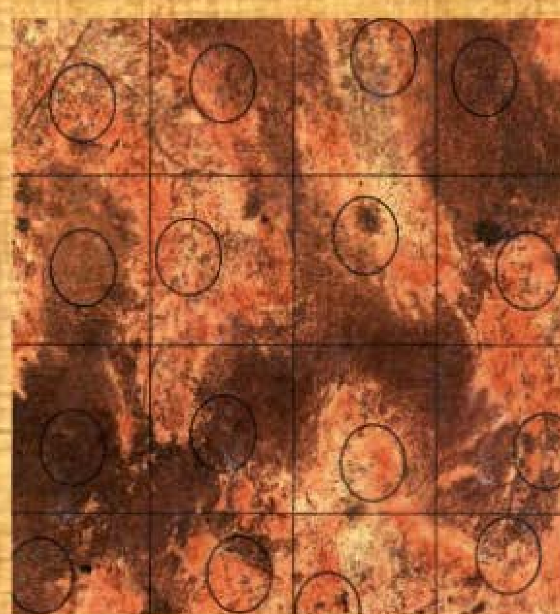
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture
Consultative Group on International Agricultural Research

TSBF

Program SUSTAINABLE LAND MANAGEMENT IN THE TROPICS

Annual Report 2009





TROPICAL SOIL BIOLOGY AND FERTILITY INSTITUTE OF THE INTERNATIONAL CENTRE FOR TROPICAL AGRICULTURE
(CIAT-TSBF)

RESEARCH PROGRAM

'SUSTAINABLE LAND MANAGEMENT IN THE TROPICS'

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TSBF Institute: Program: **'Sustainable Land Management in the Tropics'**

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I. Project overview

I.1. Introduction to the sustainable land management research programme annual report 2009

In 2009 'sustainable land management' was defined and established as a second research programme beside the 'integrated soil fertility management' research programme of the tropical soil biology and fertility research area. This was brought forward by the need to enhance programmatic coordination in response to the increasing number of activities (projects) related to sustainable management of soil resources and the need to address processes related to land degradation that take place at a landscape level. It basically elevated elements already mentioned in the TSBF strategic document related to TSBF's objectives and strategic trusts to a separate programme. The objective 'to develop sustainable land management practices in tropical areas while reversing land degradation' has particular elements that relate to land degradation that do not necessarily and exclusively relate to ISFM. The SLM programme has a wider focus on land though the emphasis remains on soil as a natural resource base. There is a gradual shift towards studying soil based processes to support provision of agricultural and non-agricultural ecosystem goods and services rather than the agricultural production function alone. Furthermore there is more attention focused towards degradation of the natural resource base and its consequences for ecosystem functioning and towards measures to mitigation land degradation and restore land and soil health. Intervention options that are investigated are at the scale of agricultural landscapes rather than management options for improved soil fertility management at the plot level, though still relying on technologies and management options developed for integrated soil fertility management. The SLM programme adopts a more area-wide approach and now proposes projects on reconstruction of eco efficient landscapes, that is landscapes that meet the need of human development (production of food and other agricultural commodities, alleviation of poverty) while conserving or improving the natural capital of soil and the ecosystems that they support.

Inventory and management of soil genetic resources of importance in that purpose will remain an important component in the SLM programme to progressively feed the knowledge base initiated with the CSM-BGBD project. Furthermore building human and social capital for research and management on the sustainable use of tropical soils and strengthening of NARS capacity remain an important component of the research programme while implementation of recommendations issued from our work through renewed public policies and market organisation will become progressively parts of our agendas.

There is still a clear link between the SLM programme and CIAT-TSBF Strategy for 2005 – 2010. However the TSBF strategy document will be replaced with strategy documents for both research programmes in 2010. This is already reflected partly in the new MTP for 2010-2012. However for the 2009 annual report we will report against the MTP for 2009-2011.

The establishment of a new research programme will require attention to be focused on staffing and capacity building, apart form the programmatic integrity, to assure that we have the skills and capacity to execute the programme as planned. For the TSBF team located in Nairobi, Africa, this means acquiring additional skills and expertise in spatial and landscape modelling. For the Latin America and Carribean region this means special efforts are being made to strengthen the group in general.

The projects that CIAT-TSBF is executing have strong ISFM components in them and the programmatic shift will be realized gradually through new projects that we will acquire. The shift will be gradual because new projects are generally won based on the recognized strength of the institute which is in ISFM research. A possible solution to this dilemma is to build strong partnerships through which the programme can still be executed. This has been the mode of operation for current projects like conservation and sustainable management of below-ground biodiversity (GEF CSM-BGBD) and the AMAZ project on Amazonian soil ecosystem services that are implemented through a large number of partners in eight tropical countries with tropical rainforest covers.

A major achievement in 2009 has been to get the Africa Soil Information Services project awarded. The project has a very strong SLM focus, though there are important elements related to integrated soil fertility management for which TSBF is responsible. The project will provide a major opportunity to embody the SLM programme and to direct strategic developments in this field. It will also serve as a model for implementing a similar objective in South America. For as yet there will be a strong overlap between, and consequently duplication in the ISFM and SLM annual reports for 2009.

TSBF aims to provide a platform function for soil research in the CGIAR and for the regions in which we operate. The SLM programme very much strives to contribute and be part of such platform to bring the importance of sustainable land management to the attention of the various stakeholders and to assure that it will contribute to relevant research for development.

I.2. RATIONALE

Land degradation has been described as one of the major constraints to food security and poverty reduction in developing countries. Despite a diversity of solutions that have been proposed and the investment of time and resources by a wide range of institutions it continues to be a substantive pervasive problem. The rural poor are often trapped in a vicious poverty cycle where land degradation is both consequence and cause of rural poverty, 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 smallholder farms is required to meet the food, feed and income needs of the poor, while opportunities to do so are constrained by a progressive land degradation problem. Degradation is widespread across Sub-Saharan Africa (physical degradation, nutrient depletion), but also in regions like Amazonia where little eco efficient extensive practices sustain farmers livelihood at expenses of natural capital leaving large areas of unproductive abandoned land. Both situations require innovative approaches to address land degradation and productivity increase simultaneously in a multifunctional approach. The reconstruction of eco efficient landscapes approach proposes to analyse and treat the different ecological, agronomic, sociological and political aspects of the problem in an integrated way. Sustainable intensification of production, optimization of ecosystem services production by managing the composition and structure of the landscape mosaic, (re)organising markets and creating synergies with public policies are the 4 elements of the multi-disciplinary approach to be implemented.

There are different pathways and intervention options to achieve **sustainable intensification and diversification of agricultural production** and these interventions can only be successful if they take account of the environmental and socio-economic conditions and if there is an enabling environment in terms of input and output markets, institutions and policies. Intensification and diversification requires sustainable land management practices and technologies but adapted to local circumstances, improved targeting of these interventions, support functions and incentives that will enable the adoption of these technologies and management options. Recognition that areas are of varied potential for agricultural production *vis á a vis* provision of other ecosystem goods and services will have to shape decisions regarding intensification and diversification of the agricultural production and promotion of sustainable agro-ecological intensification. Win-win approaches in which both components will be improved and support each other will be developed.

In order to address land degradation we need to look at the larger **agricultural production landscape** (that comprises the bio-physical, socio-economic and the cultural and political landscape). The production landscape, that is the composition and structure of the landscape mosaic in different types of productive and non productive land uses, needs to be understood, not only in terms of agricultural production, but in terms of the provision of environmental (or ecosystem) goods and services (of which food production is one). We embrace the concept of **soil health** that indicates the capacity of the soil ecosystem to provide soil related ecosystem goods and services. Of interest is then the productive capacity of these landscapes that is directly linked to its resource base. Of concern is the eroding resource base in many of these production landscapes in Africa, Central America and Amazonia where most of our research is conducted. An operational definition of soil and land health is required, including indices that describe health status that should consider soil biological, chemical and physical degradation of the soil as well as in terms of erosion and loss of soil biodiversity and associated ecosystem services.

The erosion of the resource base is not only a concern of the farmer but of the wider stakeholder community that depend on the ecosystem services for their livelihoods. Solutions for land degradation need therefore involve both the farmer communities as well as the wider stakeholder groups. In many cases farmers have options to counteract the eroding resource base, by intensifying the production system (applying fertilizer, mechanization of the tillage operations for example) or increasing the land under cultivation. However, the trade-offs are evaluated at a different scale. As options are available to the farmer, the challenge might be to develop technologies and intervention options for **intervening at the landscape level**, to maintain or improve the resilience of the productive capacity of the soil to **climate and environmental change**, apply the concept of integrated natural resource management (INRM) to the larger landscape to reshape eco efficient landscapes.

The SLM research programme aims to identify domains of potential adoption and improvement of technologies for increasing soil productivity, preventing degradation and for rehabilitating degraded lands. One major outcome will refer to tools and methods to be used for that purpose. In line of the above, thresholds for assessing soil health status need to be identified. These thresholds need to inform about whether soil degradation has progressed beyond a stage where the soil is no longer responsive to management options available to the farmer and where soil restoration or rehabilitation is needed that will generally require the

intervention of (or regulation by) government authorities or other stakeholders. The interventions need to be designed accordingly.
To improve soil quality and sustain increases in productivity and provision of environmental services requires greater understanding of **processes that govern soil quality** and trends in soil quality within the landscape. This means understanding how the landscape functions as an integrated system where the interaction between components is as important as dealing with the components themselves. Novel conceptual models, tools and techniques for integrated natural resource management need to be designed and implemented. The components refer to land use and management, soils, water and pest and diseases, biodiversity and other, and the system describes the interactions between these components. This concept can be applied to various scale levels, whereby for compound spatial units lateral (resource) flows also have to be taken into account. . It requires understanding of the **spatial *and temporal* variation in the various aspects of soil and land health**.

Research challenges remain as how to **model the interactions between the landscape components.** These resources relate to water, to **organic matter, to biological resources (biodiversity)**, but also to labour and capital. Spatial and temporal variation in soil biodiversity and its implications for the provision of soil related ecosystem services is still virtually unchartered terrain and will remain a focus of the research programme.

The 'sustainable land management' research programme is part of the Tropical Soil biology and Fertility research area. The SLM research programme will link and build upon results obtained from the research programme on decision support and policy analyses (DAPA) to improve the effectiveness of agricultural research and development and the uptake of research results by small scale farmers and will solicit support especially in the field of successful targeting, reaching end users and impact assessment. Strengthening the organizational capacities of farmer organizations (including women's producer organizations) and rural service providers will be instrument to the success of the SLM research programme. Issues related to social capital will be addressed mainly through this research programme.

The goal 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 America, while optimizing production of ecosystem services in renewed landscapes, 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, developing knowledge sharing and formation among all stakeholders and contributing to agricultural policy formulation and development.

The objective of the SLM research programme is "To enhance knowledge and understanding of land and soil health important to sustainable agricultural production in tropical landscapes, and to demonstrate that by improved targeting of land use and soil management interventions trends in the erosion of the soils resource base can be reversed and benefits can be achieved in gains in sustainable agricultural production through enhanced provision of soil ecosystem goods and services".

The SLM research programme has defined 5 outputs to satisfy the objectives and goals defined. For the implementation of activities to generate these outputs the SLM research programme depends on projects that will address part or some of these outputs. The implementation of the activities planned for the period 2009 – 2011 is partly based on existing project that will mature during the planning period and partly on projects that are either in the pipeline or are in the stage of proposal writing. The following are the desired outputs:

- **Output 1 SOIL PROCESSES:** Biophysical processes and principles that underlie soil and land health; processes of soil degradation, drivers and proximate causes of soil degradation understood; principles for restoring soil biological quality and soil health defined, with emphasis on soil biological processes and the interaction with soil physical and chemical components (including soil organic matter) in agro-ecosystems.
- **Output 2 ECO-INTENSIFICATION:** Economically viable and environmentally sound soil management practices developed and tested, integrating knowledge of biophysical, socio-cultural and economic processes, with emphasis on direct and indirect management of soil biological resources for low- and medium external input agricultural systems.
- **Output 3 ECO-EFFICIENT LANDSCAPES** : Socio-economic and cultural drivers for land degradation identified and constraints mapped; Options for sustainable land management and reversal of soil degradation for social profitability developed and application domains identified
- **Output 4 MODELING**: Decision support tools for improved targeting of recommendation for sustainable land management and negotiation support; Institutional environment and support services required for sustainable land management identified and policy recommendations.
- **Output 5 CAPACITATION:** Stakeholder capacity to advance the development and adaptation of recommendations for improved land management enhanced; effective dissemination of results and advocacy for sustainable land management

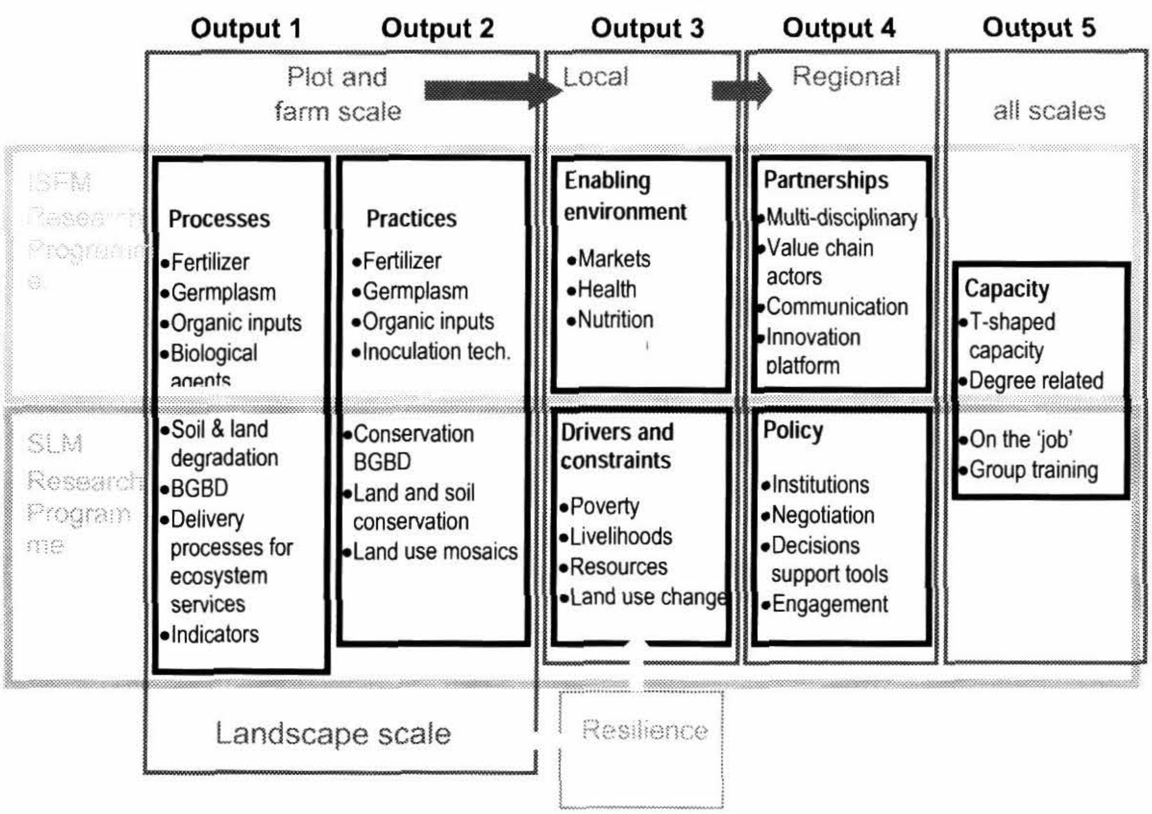

Figure 1: Specific focus areas of the ISFM and SLM Research programmes

The ISFM and SLM research programmes are strongly interlinked as both aim for sustainable agricultural productions systems, however with **ISFM research programme** putting an emphasis on the nutrient management for enhanced agronomic efficiency and production, focusing on plot and farm scales, whereas the SLM outcome emphasizes the management of soil biological resources and has a focus on the landscape scale. The SLM research programme does not have an exclusive focus on production systems like the maize-based production systems, millet and sorghum based system or cassava based system, though they are the major cropping systems for the impact zones TSBF has defined. Alternative crops and land use options may constitute an important element in the strategy to improve land and soil management.

Support is required from other CIAT research programmes in developing decision support tools that will help in shaping "decisions in landscape, water and soil management". Work on integrated production systems and collective action; trade-off analyses, payment schemes for ES will be important complementary activities; Information on climate risks and vulnerability to climate change, incidence of poverty, information on crop suitability including incidence and crop vulnerability to soil borne pest and diseases, and other will inform prioritization of study areas and in general in formulation of policy recommendations.

I.3. Alignment to CGIAR System Priorities:

CIAT-TSBF's research programme on Sustainable Land Management 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,* and **Priority Area 4D**: Promoting sustainable agro-ecological intensification in low- and high-potential areas. With activities contributing to the following specific goals of **PA 4A**:

- **Specific goal 1:** *To develop analytical methods and tools for the management of multiple use landscapes with a focus on sustainable productivity enhancement*
- **Specific Goal 2:** *To enhance the management of landscapes through changing stakeholder awareness and capacity for social-ecological planning at landscape and farm levels*
- **Specific Goal 5:** *Creating multiple benefits and improved governance of environmental resources through the harmonization of inter-sectoral policies and institutions.*

With respect to the System **Priority Area 4D** the following specific goals are being served:

- **Specific Goal 1**: *To improve understanding of degradation thresholds and irreversibility, and the conditions necessary for success in low productivity areas*
- **Specific Goal 3**: *To identify domains of potential adoption and improvement of technologies for improving soil productivity, preventing degradation and for rehabilitating degraded lands*
- **Specific goal 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*
- **Specific Goal 7:** *To optimize productivity at high input use (e.g. labour, nutrients, pest control practices, water, seed, and feed) through understanding and managing spatial and temporal variation.*

I.4. IMPACT PATHWAYS

The five major outputs described above are the main pathways through which the SLM research programme aims to generate impact. All the five outputs represent enabling conditions that are required to affect change in land use and soil management. These conditions include: 1) appropriate information and knowledge on status of land degradation, the accurate diagnosis and understanding of causes, constraints and opportunities surrounding land degradation; 2) appropriate land and soil management technologies and options for the various stakeholders for intervention at plot and landscape level; 3) enabling environment that provides access to necessary services and access to resources; this may refer to proper market infrastructure, access to markets, access to land and other resources, as well as access to technologies etc.; 4) government policies and support structures (institutional infrastructure) that allow for the implementation of sustainable soil and land management policies (investment in sustainable land management), that address the drivers of land degradation and provides incentives for the adoption of improved soil and landscape management practices and assures that benefits from proviso of ecosystem good and services are shared (e.g. reward mechanisms for environmental goods and services) and finally 5) Capacity building through formal training components as well as stakeholder workshops and generation of international public goods. First of all tools and techniques need to be available for assessing the problems related soil and land degradation and degrading ecosystem goods and services and the impact this has on the livelihood and well being of people. It is only when reliable and convincing data is presented that investments in land rehabilitation and restoring agro-ecosystems will be considered.

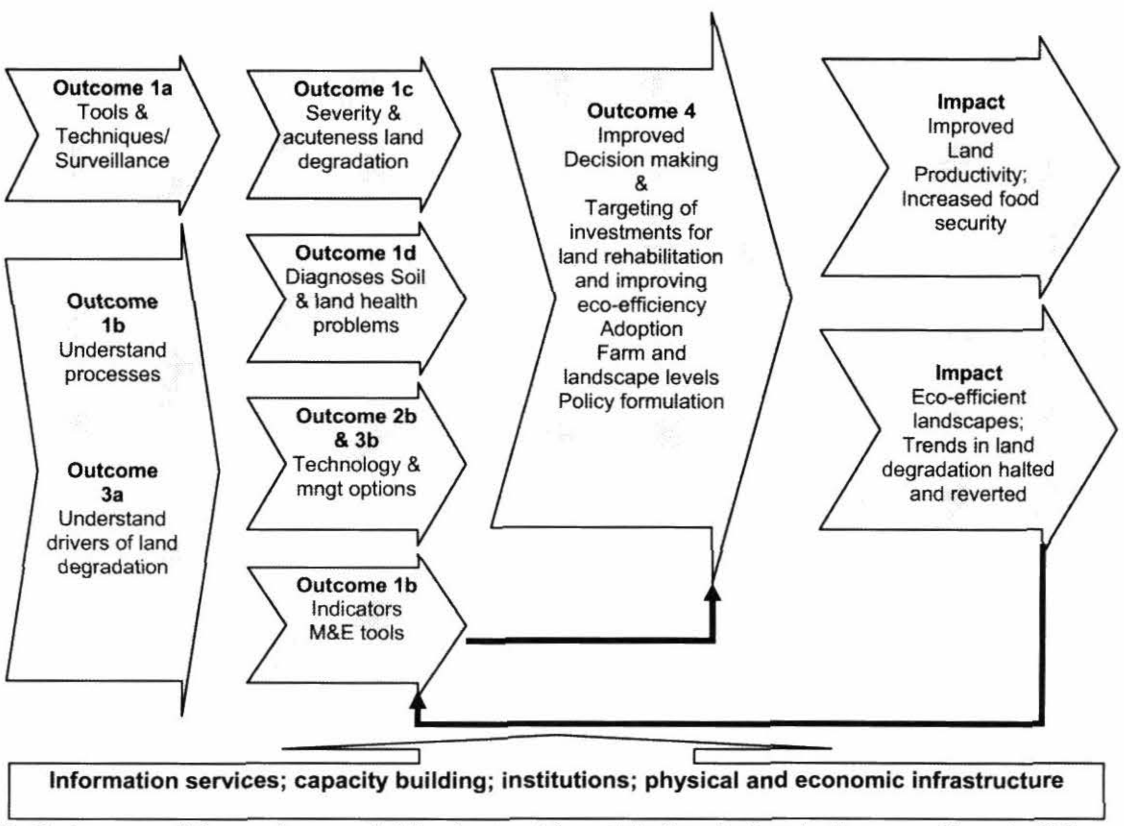

Figure 2: Outcomes of the various activities (outputs) and their relation to the overall goal of the SLM Research programme indicating the impact pathway

Improved understanding of the processes will assist in the diagnoses of the problems and in identifying the entry points for addressing these. It is also based on the improved understanding of the processes that will allow for the development of appropriate technologies and identification of successful management options. It also will provide the tools and techniques for monitoring and evaluation of soil and land health status (indicators). All the above will contribute to improved decision making in investments to be made, whether this will be in research to provide diagnostic tools, in technology development, in capacity building, or infrastructural development; for the farmer to make better decisions in the technology to invest in or choose between the various management options. This will lead to improved land productivity, increased food security and wellbeing, but only if there is a flow of information and only if data and information reaches the user in a form and content that is applicable to that user. Further user must have the capacity to understand and act upon the information provided. The impact pathways are depicted in **(Figure 2)**.

I.5. INTERNATIONAL PUBLIC GOODS

The IPG produced by the SLM research programme include the following:

- Improved understanding on soil (biological) processes;
- Inventory of below-ground biodiversity in major tropical eco-regions;
- (Standard) methods for the inventory and characterization of BGBD
- Improved understanding of loss of BGBD in relation to the intensification of land use;
- Improved knowledge on how different stakeholders create and manage landscapes;
- Indicators of soil (biological) quality;
- Improved approaches and practices for managing soil, water and land resources at a landscape level;
- Innovative diversification options of land use within agricultural production landscapes;
- Decision support tools and models to optimize landscape composition and structure through analyzing trade-offs among food productivity, ecosystem services and land conservation;
- Institutional innovations and policy options to reduce land degradation and to restore degraded lands facilitated by synergies created among research, farmers and policies.

The Institute has a comparative advantage in conducting and coordinating IPG research on soil biology and fertility in a farming system and land use system context, where land degradation undermines local livelihoods. However, while CIAT-TSBF will focus primarily on strategic research, it will support technology dissemination and development activities with partners via regional networks and global projects. CIAT-TSBF SLM 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 is in its second phase of project implementation and a set of projects ending or starting in Latin America, mainly - although not exclusively - focused on hillside systems and Amazonian deforested areas. Much of the applied research and dissemination of findings, as well as NARSs capacity building, will be done in Africa via the Institute's regional partner network — the African Network for Soil Biology and Fertility (AfNet). CIAT-TSBF also collaborates with the South Asian Regional Network (SARNet) on soil fertility research in that region. Efforts will be undertaken to build a similar network for soil biology and fertility research in Latin America

II. Annual Report 2009 summary

II.1. SLM research programme logframe

Targets	Outputs	Outcome and Impact
Output 1	Description: Biophysical processes of soil degradation and principles that underlie soil health; Root and proximate causes of soil degradation; Principles and concepts for restoring soil biological quality and soil health defined. Intended users: CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia.	Outcome: Understanding of soil processes important to provide soil ecosystem services informs the development of technologies and management options (see output 2). Impact: Standard methods and indicators help assessment of soil health status in uniform and consistent manner and allow for identification of soil health problem and create awareness of severity of the problem and generate action preparedness among stakeholders.
Output Targets 2009	Practical methods for rapid assessment and monitoring of the soil resource base status in relation to soil nutrients, organic matter, aggregation and soil structure.	Standard methods allow for comparing between regions and global and regional assessment of soil health status.
	Standard methods for the inventory of BGBD documented (handbook published).	Information on methods for the inventory widely available. Standard methods widely used and cited in inventory studies.
	BGBD assessed in 11 benchmark sites across the Tropics and loss of BGBD as result of land use intensification determined; Assessed of soil health status in agric prod. landscapes of major agro-ecological impact zones.	Status of BGBD in benchmark sites across major impact zones documented and possible consequences for sustainable production identified; Awareness of the status of the soil resource base increased leads to enhanced action preparedness to protect the soil resource base.
	Indicators of soil (biological) quality identified and documented.	Tools available for rapid assessment and monitoring of soil health status; Adoption of indicators leads to increased capacity (and awareness) of stakeholders to assess and monitor soil health status.
	Concepts of valuating the contribution of soil biota and biotic processes to the provision ecosystem goods and services applied in case studies.	Documented value of BGBD and soil biological processes assists in recognition of the importance of soil biodiversity and create willingness to protect these resources.
Output Targets 2010	Modelling tools to predict effect of soil management interventions and technologies on soil health status developed and validated.	Models help to determine realistic and viable solutions to soil health problems and help to determine possible investment options and decision making.
	Methods for evaluating soil health status (provision ecosystem goods and services) developed and accepted.	Methods allow attaching value to land and soil degradation and improve decision on intervention.
	The social, gender, and livelihood constraints and priorities affecting the sustainable management of soils identified especially in relation to improved SOM management and management of BGBD.	Partners are working to overcome the identified constraints with new proposals and on-going research.

Targets	Outputs	Outcome and Impact
Output Targets 2011	Decision support framework for targeting soil management recommendation (ISFM and INRM technologies) at landscape level established.	Partners use decision support framework for improved targeting of ISFM and IRNM technologies and increases likelihood of success of the interventions.
	Tools and techniques for rapid appraisal of soil health status and gradients at landscape level developed.	Partners use tools for assessment of soil health status of various production landscapes.
	Tools and methods developed for rapid appraisal of agricultural production landscapes especially with respect to socio-economic drivers for land and soil degradation and socio-economic constraints for improving soil productivity and soil health; mapping of the socio-cultural and policy environment (production potential, social & human, economic, natural capital).	(National) Partners use framework and tools for landscape planning in selected tropical agricultural productions landscapes.

Targets	Outputs	Outcome and Impact
Output 2	Description: Economically viable and environmentally sound soil management practices developed and tested, with emphasis on direct and indirect management of soil biological resources for low- and medium external input agricultural systems. Intended users: CGIAR, ARI, researchers from NARS and local universities, NGOs, farmer groups, private sector agents, extension services, and regional consortia, conservation agencies.	Outcome: Technologies and soil management strategies available for range of agro-ecological and socio-economic conditions provides viable options for various stakeholder groups and increases adoption of improved technologies. Impact: Increased sustainability of productions systems and improved security of farmers in target impact areas.
Output Targets 2009	Local baselines and interviews show that farmers' understanding of soil biological processes and soil health status is demonstrably enhanced in at least 5 benchmark sites.	Farmers adopt direct and indirect management options for management of BGBD and soil health.
	Direct and indirect options to manage BGBD that enhance locally important ecosystem services demonstrated.	Increased awareness among local stakeholders of the benefits of conserving and managing BGBD Evidence based decisions on investment in indirect management for improving soil health.
	Alternative production systems like Conservation Agriculture tested and evaluated for effectiveness in maintaining and restoring soil health and with respect to adoptability.	Evaluation of CA will contribute to improve targeting of CA as alternative strategy for sustainable agricultural production and increase adoption.
***Output* Targets 2010**	Alternative crops and integrated systems investigated for their effectiveness in maintaining soils resource base.	Demonstration of success of more integrated productions systems and crop diversity will stimulate farmers to adopt more diverse systems and enhance productivity.
	The role of soil organic matter in regulating BGBD and soil health tested across a number of experimental sites in at least 5 countries in the tropics.	Partners are adapting soil fertility management practices to support specific soil organic matter-related functions.
	Species/strains identified with potential for inoculants development; Direct inoculation in various cropping systems and for various purposes (enhancing productivity, control of soil	Partners explore options for biological means to improve soil productivity and soil health status and possible commercial production of inoculants. Research into use of biological resources for inoculum development strengthened.

	borne pest and diseases and improving soil structure) tested on persistence, affectivity and competitiveness	
Output Targets 2011	Tools for modeling resource allocation within agricultural productions landscapes and optimization of resource reallocation suggested for selected agricultural production landscapes.	Partners realize that measures taken at landscape level may sort better affect and adjust their strategies for soil resource conservations; Collaborative action and community based interventions stimulated Better use of resources leads to enhanced productivity.
	Improved production systems (including technologies) and having multiple benefits of food security, income, human health and environmental services documented and characterized in terms of application domains.	Documentation on productions systems and technologies (soil and land conservation, inoculation, soil organic matter management, fertilizer technologies etc) easily accessible and allows for consideration of variety of alternative solutions to soil health related problems.

Targets	Outputs	Outcome and Impact
Output 3	Description: Socio-economic and cultural drivers for land degradation identified and constraints mapped; Options for sustainable land management and reversal of soil degradation for social profitability developed and application domains identified. Intended users: CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers.	Improved diagnosis of soil health problems informs identification of entry points and targeting of soil and land management interventions.
Output Targets 2009	Methods, protocols and indicators developed to characterize socio-cultural and economic environment and for valuation of soil ecosystem services.	Indicators and standard protocols inform rapid rural appraisal and diagnoses of soil health related problems in agricultural productions landscapes.
	Socio-economic constraints to soil health management assessed in some agricultural productions landscapes and forest margins of the BGBD project; diagnostic carried out.	Information on relative importance on socio-economic constraints informs policy formulation for targeted areas.
	Methods developed for socio-cultural and economic (participatory) valuation of ecosystem goods and services developed and implemented in BGBD project sites.	Enhanced appreciation by farmers in the study sites of soil related ecosystem services enhances adoption potential for improved soil (BGBD) management. And effective decisions on protection of soil biological resources.
Output Targets 2010	30% of partner farmers in pilot sites use SLM options that arrested resource degradation and increased productivity in comparison with non-treated farms.	Increased productivity and conservation of degraded landscape.
Output Targets 2011	Scale-up research on soil fertility gradient to farm and landscape levels by conducting one or two carefully designed, integrated studies in collaboration with other CIAT scientists.	Generalize the findings from on farm level gradients in soil fertility into generic rules and tools that can be used in guiding ISFM in practice across landscapes.

	Landscape dynamics assessed social and economic constraints to improved land and soil management assessed application domains and options for improved soil and land management identified for the majority of the TSBF project sites.	Diagnosis inform of long term strategies for improved productivity, soil resource conservation and restoration in the target areas within the *impact zones*.

Targets	Outputs	Outcome and Impact
Output 4	Description: Decision support tools for improved targeting of recommendation for sustainable land management and negotiation support; Institutional environment and support services required for sustainable land management identified and policy recommendations. Intended users: Researchers from NARS, NGOs, Extensions services, policy makers, donor community.	Principles of sustainable land management integrated in local and country policies and programs and investment plans; Strategy documents inform Donor community on possible investment options and ultimately reversed land degradation contributes to global SLM goals.
Output Targets 2009	Farmer-to farmer knowledge sharing and extension through organized field trips and participatory M&E activities conducted in TSBF SLM project sites.	Farmers realize benefits of knowledge sharing; enhanced capacity to adopt and adjust technologies for sustainable land management.
	Trade-off analyses conducted and policy recommendation issued for the BGBD benchmark areas.	Policy makers aware of the importance of conservation and sustainable management of BGBD; conservation of soil biological resources included in local policies contribute to sustainable utilization of soil biological resources.
Output Targets 2010	Profitable land use innovations scaled out beyond pilot learning sites through strategic alliances and partnerships, and application of alternative dissemination approaches.	Partners incorporating new knowledge and skills in new proposals and on-going research efforts.
	Decision support framework for soil and land use management recommendation developed and validated in pilot learning sites in 5 countries in SSA.	Application of decision support framework help stakeholders to target interventions and defined their investment plans;
	Strategies for institutionalization of participatory NRM approaches and methodologies established.	New institutional arrangements catalyze multidisciplinary work and enhance scaling up of technologies and best practices.
Output Targets 2011	Social science aspects are included in the decision-making process and tools to better understand actionable management strategies for landscape management, their knowledge requirements, and economics.	CIAT-TSBF expands its social science activities regional hubs in Southern and Central Africa and few agro-ecosystems of major importance.

Targets	Outputs	Outcome and Impact
Output 5	Description: Stakeholder capacity to advance the development and adaptation of recommendations for improved land management enhanced; effective dissemination of results and advocacy for sustainable land management. Intended users: CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, 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 2009	Web content of the BGBD website enhanced to contain data and information on taxonomy and species identification, methods for inventory and characterization of BGBD, Synthesis reports on inventory, indicators of BGBD loss and soil biological quality indicators and management option and techniques for managing BGBD.	Increased number of biodiversity scientists and practitioners use the website as resource base for information on BGBD (for inventory and management).
	Documentation on integrated approach to the management of agricultural production landscapes with respect to soil health and conservation of the soil resource base.	Different partners linking food security, income generation, environmental health to human wellbeing at landscape level.
Output Targets 2010	Validated intensive and profitable systems are being demonstrated, promoted by partners and adopted by farmers in 10 countries.	Increased sustainable productivity and profitability of major cropping systems.
	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.	Farmers and other stakeholders empowered in use results of trade-off analysis to better negotiate for support services and policy formulation for sustainable production.
	Stakeholder workshops in selected productions landscapes involving national and local stakeholders, presenting recommendations for improved soil and land use management.	Values attached to ecosystem services are shared by various stakeholder groups and provides basis for collective action to conserve and manage soil resource base.
	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.	Improved knowledge sharing and exchange to empower stakeholder to innovate with respect to technologies and best land conservation practices.
Output Targets 2011	Improve linkages with the private sector to improve access to fertilizer and develop recommendations for its use by farmers and other stakeholders involved.	Potential adoption and impacts of mineral fertilizers in ISFM by farmers and agro dealers increase.
	Demonstration and documentation of successful cases prove approach and methodology used and will generate additional funds for out scaling of the activities (donor buy-in) NGO adopt methodology and will lead to improved adoption and policy formulation.	Arrest of resource degradation and restoration of soil resource base in targeted production landscapes and increased productivity and well being of farmer communities; Partners scale up collaborative research on soil health and restoration of soil resource base in well designed and fully integrated studies.
	Degree training (BSc, MSc and PhD) on relevant topics.	150 students from developing targeted countries have received degrees through involvement in SLM projects.
	Short term training courses (methods for inventory of BGBD, Decision support tools for recommendations on soil and land use management, Economic valuation and PES, etc.).	Scientific capacity in national partner institutions enhanced.

II.2. OUTPUT TARGETS FOR 2009

II.2.1 Standard methods for rapid assessment and monitoring of the soil resource base status allow for comparing between regions and global and regional assessment of soil health status

Status: Fully Achieved.

The AfSIS project has been launched in January 2009 and has received worldwide media coverage. The first year of the project has been devoted to defining the technical specifications for the Africa Soil Information Services, i.e. developing the manuals, formation and training of the regional teams that are going to the soil health surveillance and the teams that will that will implement the multi-location diagnostic trials, establishment of the laboratories and training of staff and making necessary (formal) arrangements that will allow us to operate in the various countries in the SSA continent. The diagnostic trials have started in Mali and Malawi and also the soil health surveillance work has been initiated.

The project has been widely advertised through publications and presentation at international events, in which also the concepts behind and technical approach to the Africa Soil Information Services has been explained. It has resulted in buy-in from various organizations (AGRA, CIALCA, and University of Bloemfontein) that have adopted the approach for their own diagnostic purposes (either adopting the protocols for the diagnostic trials or the approach to survey of sentinel sites of soil health status). The project is part of a global consortium, GlobalSoilMap.net, and has been able to establish nodes for other continents outside Africa and raise additional funding for these nodes (e.g. $52 million for the Eurasia node).

Publications:

- MacMillan et al., 2009. GlobalSoilMap.net: A new digital soil map of the world. Pedometrics 2009. Beijing, China. August, 2009.
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Minasny, L. Montanarella, P. Okoth, C.A. Palm, J.D. Sachs, K.D. Shepherd, T. Vågen, B. Vanlauwe, M.G. Walsh, L.A. Winowiecki & G.L. Zhang, 2009 Digital Soil Map of the World. Science 325: 680-681.

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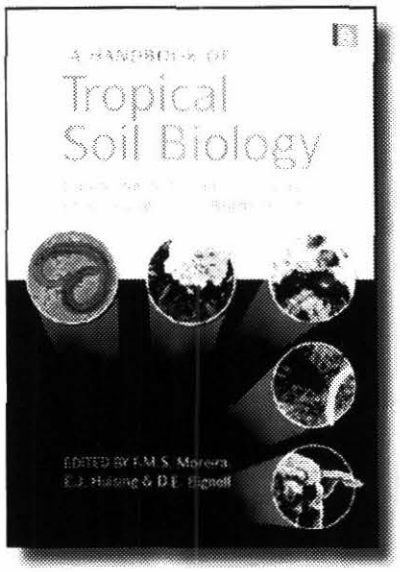
Invited presentations at international meetings

- Measuring carbon in tropical agricultural landscapes. 8th African Growth and Opportunities Act (AGOA) Forum, August 6, 2009, Nairobi, Kenya.
- The production of ecosystem services by soils: a conceptual model. SERI World Conference on Ecological restoration, Perth Australia, Aug. 24, 2009.
- Managing ecosystem services in agricultural landscapes: The African challenges. Aug. 25, 2009. 2nd World Agroforestry Congress, Nairobi, Kenya.
- A new soil information system for Africa: Why and how? Oct. 24, 2009. East Asian Soil Science Society Meeting, Seoul, Korea.
- A new soil information system for Africa: Why and how? University of the Freestate, Strategic Research Cluster Launch. Nov. 22, 2009. Bloemfontein, Republic of South Africa.
- La metodología que se está usando en Africa". XVIII Congreso Latinoamericano de la Ciencia del Suelo, San Jose, Costa Rica. November 18, 2009.
- Spectral methods for monitoring soil carbon in landscapes. Dec. 15, 2009. COP15, Copenhagen, Denmark
- La visión del CIAT sobre suelos en Latino America y Carribe. XVIII Congreso Latinoamericano de la Ciencia del Suelo, San José, Costa Rica. Dec 2009.

II.2.2. *Information* on methods for the inventory of below-ground biodiversity available. Standard methods widely used and cited in inventory studies.

Status: Fully Achieved.



The 'Handbook of Tropical Soil Biology, sampling and characterization of below-ground biodiversity' was published in October 2008, by Earthscan. It was as such already reported on in the annual report for 2008. It received some very good reviews in the various scientific literatures. We do not have data on the book being cited or referenced in other publications, but we know it is being used for teaching purposes. Spanish and Portuguese translations of the book are being prepared and will be published in 2011.

II.2.3 Status of BGBD in benchmark sites across major impact zones documented and possible consequences for sustainable production identified; Awareness of the status of the soil resource base increased leads to enhanced action preparedness to protect the soil resource base

Status: Fully Achieved.

It is for the first time that a comprehensive assessment of soil biodiversity has been conducted in the biodiversity hotspots that the 11 benchmark sites of the CSM-BGBD project represent. The CSM-BGBD project is implemented in 7 tropical countries: Brazil, Mexico, Ivory Coast, Uganda, Kenya, India and Indonesia, and the benchmark sites represent ecoregions of global significance, ranging form the tropical humid forest of the Amazon to the mountain ranges of the Himalayas. In doing this systematic inventory a number of new species where discovered and the existence of some very rare species were confirmed in some of the sites.

The results from the inventory add to the knowledge base and it provides a valuable baseline or reference for future inventory studies. The results of the inventory have been reported in individual publications and reports are currently being prepared that compiles the information on the various functional groups for each of the benchmark areas. An internet accessible database is being developed that will make the data from the inventory available for interested third parties.

Publications:

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- Journal of Tropical and Subtropical Agroecosystems, special issue on the Inventory of Below-ground biodiversity in the Kenyan benchmark areas:
  - Muya E.M., N. Karanja, P.F. Z. Okoth, H. Roimen, J. Munga'tu, B. Mutsotso and G.Thuranira, 2009. Comparative Description Of Land Use And Characteristics Of Belowground Biodiversity Benchmark Sites In Kenya Journal of Tropical and Subtropical Agroecosystems, 11 (2009): 263 – 275 (http://www.veterinaria.uady.mx/ojs/index.php/TSA/issue/view/10
  - Okoth S. A., P. Okoth and E. Muya, 2009. Influence of Soil Chemical and Physical Properties on Occurrence of Trichoderma Spp in Embu, Kenya. Journal of Tropical and Subtropical Agroecosystems, 11 (2009): 303 – 312 (http://www.veterinaria.uady.mx/ojs/index.php/TSA/issue/view/10)
  - Jefwa J.M., J. Mung'atu, P. Okoth, E. Muya5, H. Roimen1 and S. Njuguini, 2009. Influence of land use types on occurrence of arbuscular mycorrhizal fungi in the high altitude regions of Mt. Kenya Journal of Tropical and Subtropical Agroecosystems, 11 (2009): 277 – 290, (http://www.veterinaria.uady.mx/ojs/index.php/TSA/issue/view/10)
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II.2.4 Tools available for rapid assessment and monitoring of soil health status (soil biological quality); *Adoption of indicators* leads to increased capacity (and awareness) of stakeholders to assess and monitor soil health status

Status: Fully Achieved.

Indicators of soil health (soil biological quality) are important tools for purpose of monitoring the soil health status and herewith important management tool. The CSM-BGBD project is currently carrying out a synthesis of the results from the inventory conducted in the 11 Benchmark sites. It will results in indicators of soil quality and it will evaluate how soil quality is related to land use and land use intensification. It will also investigate whether common indicators can be applied across the various benchmark sites and whether common trends are observed in the loss of the below-ground biodiversity. The book well be published in 2010, but some results of the analyses have been presented already on some international conferences.

The insight in the loss of BGBD provides the entry points for possible intervention and management of BGBD at landscape level. Land uses of intermediate levels of intensity of use of the land may be targeted for biological interventions in the soil management system to enhance sustainable production of crops. Like wise, for landscapes that are rather vulnerable to increasing land use intensity or for which intensification is not a feasible or desirable option, possibilities for biological interventions for a sustainable increase of land use intensity might be considered.

Publications:

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Invited presentations at international meetings

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- Jefwa, J.M., Sturmer, S., Balakrishna, Serani, S., Varela, L. Huising, J. Okoth, P, Mung'atu, J., Ichami, S., 2009. Can arbuscular mycorrhizal fungi (AMF) be indicators of soil quality? Diversitas Open Science Conference 2, Cape Town, 13-16 Oct. 2009. Book of Abstracts, p. 148, http//www.diversitas-international.org/docs/

II.2.5 Evaluation of CA will contribute to improved targeting of CA as alternative strategy for sustainable agricultural production and increase adoption

Status: 75% achieved

Conservation agriculture receives a lot of attention both in the research environment as well as from development practitioners as a possible system to solve problems of low agricultural productivity in SSA. A lot of funds are invested in the further development and in the promotion of CA, while there is not yet convincing evidence that CA works under conditions experienced in SA and for the smallholder farmer. The article cited below has contributed enormously to the discussion on CA in the scientific and development world as reflected in the blogs that have appeared in connection with the release of this paper.

Publications:

Ken E. Giller, Ernst Witter, Marc Corbeels, Pablo Tittonell, 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field crops research, 114 (1): 23-34.

Abstract: Conservation agriculture is claimed to be a panacea for the problems of poor agricultural productivity and soil degradation in sub-Saharan Africa (SSA). It is actively promoted by international research and development organisations, with such strong advocacy that critical debate is stifled. Claims for the potential of CA in Africa are based on widespread adoption in the Americas, where the effects of tillage were replaced by heavy dependence on herbicides and fertilizers. CA is said to increase yields, to reduce labour requirements, improve soil fertility and reduce erosion. Yet empirical evidence is not clear and consistent on many of these points nor is it always clear which of the principles of CA contribute to the desired effects. Although cases can be found where such claims are supported there are equally convincing scientific reports that contradict these claims. Concerns include decreased yields often observed with CA, increased labour requirements when herbicides are not used, an important gender shift of the labour burden to women and a lack of mulch due to poor productivity and due to the priority given to feeding of livestock with crop residues. Despite the publicity claiming widespread adoption of CA, the available evidence suggests virtually no uptake of CA in most SSA countries, with only small groups of adopters in South Africa, Ghana and Zambia. We conclude that there is an urgent need for critical assessment under which ecological and socio-economic conditions CA is best suited for smallholder farming in SSA. Critical constraints to adoption appear to be competing uses for crop residues, increased labour demand for weeding, and lack of access to, and use of external inputs.

II.2.6 Eco-efficient land and soil management practices and technologies evaluated and documented, with their application domains specified

Status: 100% Achieved.

The knowledge and principles generated by CIAT and its partners in Central America confirm that the Quesungual Slash and Mulch Agroforestry System (QSMAS) can be a model production system for implementing conservation agriculture to achieve food security and sustainable development in drought-prone areas of hillsides in the sub-humid tropics, while providing ecosystem services in the face of land degradation and climate change. As an adoptable option to replace the slash and burn traditional system, QSMAS can improve smallholder livelihoods through eco-efficient use and conservation of natural resources. Participatory validation activities suggest that the conservation agriculture principles embedded in QSMAS can be readily accepted by resource-poor farmers and local authorities in similar Agroecosystems.

II.3. HIGHLIGHTS FOR 2009

II.3.1 Launch of the African Soil Information Services project

The official launch of the Africa Soil information Services (AfSIS) was held in January 2009. The project was approved in 2008 and officially started as per the first of November 2008. The project is funded by the BMGF and AGRA with a total budget of US$18.1. The international launch was attended by a large number of international guests from institutions that partner in the GlobalSoilMap.net and prospective partners and collaborators in the project. The launch included a press conference and a press release was issued. The launch of the project was covered by media from all over the world and many interviews were given by the various members of the project team.

naturenews

Published online 13 January 2009 | Nature | doi:10.1036/news.2009.17

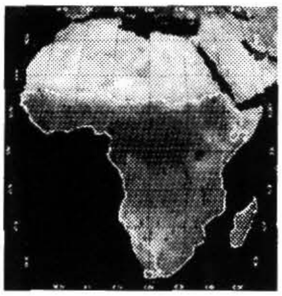
News

Digital soil map for Africa launched

Map will help farmers to improve crop production.

Natasha Gilbert

Soil scientists are developing the first ever digital soil map of Africa, covering 42 countries south of the Sahara. The map will provide up-to-date information on the health and properties of the soil, helping farmers and policymakers to improve degraded soils and increase crop production.



The map covers 42 African countries.

CIAT

The map will be made from satellite measurements of soil nutrients, moisture and organic matter. These data will be combined with samples taken over the next four years at 60 randomly chosen sites across sub-Saharan Africa, where researchers on the ground will measure the soil's chemical and physical properties and its organic content.

Using this information, scientists can predict soil properties at places they have not sampled, checking their models by comparing predicted soil properties against actual measurements. The map will also incorporate existing soil maps and information on geology and climate.

A farmer in Malawi, for instance, could use the map — which will be freely available online — to find out how much fertilizer, and of what type, his or her land needs. The project is also looking into sending information to mobile phones, which are very common in Africa.

The map will divide the continent into squares that measure 90 metres x 90 metres — giving 100-times greater resolution than the best current maps of African soils, say scientists.

Valuable update

"This is a quantum leap," says Alfred Hartemink, a soil scientist at ISRIC — World Soil Information, an independent foundation in Wageningen in the Netherlands, and one of the scientists leading the project. "With these maps we can now produce quick, cheap and accurate information."

Poor knowledge of soil conditions has hampered efforts to improve African soils, which are some of the most depleted on Earth, Hartemink says. Existing soil maps are incomplete and date from the 1960 and 1970s, he says.

"This project will benefit farming families in Africa by showing how they can reverse declining soil fertility, a major reason for slow growth in the region's agricultural productivity during recent decades," says Namanga Ngongi, president of the Alliance for a Green Revolution in Africa based in Nairobi, Kenya, a partnership to promote sustainable agriculture in Africa.

The mapping project, called the African Soil Information Service, is launched today at the Tropical Soil Biology and Fertility Institute in Nairobi, which is leading the initiative. The institute is part of the International Centre for Tropical Agriculture, a non-profit research body funded by international organizations and private foundations.

The African initiative is the first phase of a bigger project to develop a global soil map, called GlobalSoilMap.net, which will be launched in New York next month.

II.3.2 Reconstruction of eco efficient landscapes in deforested Amazonia. Lessons from the AMAZ project.

The future of Amazonia forest may well depend on the way the 30% already deforested land is used as much as on direct protection efforts. We still have no idea of the comparative eco efficiency of different landscapes built in these areas and less so of how to build landscapes that will meet the challenges of human development and global change in the next two decades.

The AMAZ project

The objective of the AMAZ project was to identify the socio economic determinants of the production of goods and soil borne ecosystem services, via landscapes constructed by people and the biodiversity that inhabits these landscapes. Over 2000 variables have been measured to evaluate the socio economic environment, landscape metrics, biodiversity, productions and ecosystem services (soil quality indicators, C sequestration, hydric services and soil chemical fertility).

These variables were measured in a sampling protocol that provided fully compatible sets of quantitative or semi-quantitative data that allowed comparisons based on multiple co-inertia analysis. In each of six landscape windows with different ages of deforestation and different colonization histories, from Para (Eastern Brazil) and Caqueta (Colombian Andean piedmont), Socio economic parameters and landscapes were described in 50 farms. In a set of 9 farms representative of each window, biodiversity of 8 groups (plants, birds, Drosophilidae, Saturnidae, earthworms, termites, ants and soil macrofauna), agro sylvo pastoral productions and soil borne ecosystem services (C sequestration, hydric functions, chemical fertility) were measured in 5 points representative of each farm.

Socioeconomic, landscape, biodiversity, productions and ecosystem services significantly covary

Multiple co-inertia analysis showed significant covariations among the different sets of data. Groups of people belonging to a given socioeconomic categories therefore build specific types of landscapes that host different biodiversities, have specific productions and provide different amounts of ecosystem services. Further analyzes will detail these results and describe the landscapes created by different groups of farmers belonging to different socioeconomic types, biodiversity that inhabits these landscapes, productions and soil ecosystem services.

Eco-efficiency of farms and landscapes

A major outcome of the project is the measurement of eco-efficiency at farm and landscape levels. It is well known that some production systems are more efficient at producing commodities and generating incomes than others, while impacts on the environment also vary.

We propose a formula to assess this eco efficiency and thus compare the impact of production systems produced by different types of socioeconomic groups on landscapes, productions and environment parameters.

Eco efficiency: $E_f = P_e * S_q * B_d$ with E_f= income $ /ha used/labour UTE unit; S_q : soil quality (GISQ index; Velasquez et al., 2007) 0.1 to 1.0; B_d : Biodiversity index (0.1 to 1.0) calculated in a similar way.

This formula was used to compare eco-efficiency of farms from the three different dominant production systems in Colombia.

The AMAZ project showed the importance of landscape, a construction of human communities that may have very contrasted performances in terms of productions, conservation of biodiversity and provision of ecosystem services. AMAZ provides a methodology for diagnostic of the different elements of eco efficiency and a way to individually assess farms and landscapes. The methodological and conceptual progress thus made allows envisaging a next step that is the reconstruction of eco efficient landscapes.

After a diagnostic phase derived from the AMAZ project, although much reduced, a model based on data set created during the diagnostic is built. This model serves as a tool in a participative exercise of optimization of the landscape that will identify the landscape components and composition of the mosaic that best allows production of goods and ecosystem services. The next step consists in reconstructing the landscape and organizing markets for the new products thus made available. During the whole process, narrow link is maintained with policy makers in order to create synergies between the project considered as a full scale experimental situation and developing policies to create incentives and/or markets for ecosystem services.

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II.4. Publications for 2009

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Bruno Lima Soares- Eficiência simbiótica de estirpes de bactérias fixadoras de nitrogênio de diferentes procedências em caupi [*Vigna unguiculata* (L.) Walp] e sua identificação. [Symbiotic efficiency of nitrogen-fixing bacterial strains from diverse origins in cowpea [*Vigna unguiculata* (L.) Walp] and their identification) Dissertação em Solos e Nutrição de Plantas (MSc Thesis Soil Science and Plant Nutrition) Soil Science Department, UFLA Lavras – MG, February 26th , 2009, 56 p. Supervisor Dr. Fátima M. S. Moreira.

Divya Dangwal. (2009). Assessment of productivity, nutrient uptake and nitrogenase activity in three selected mountain legume crops under mixed and mono cropping. Department of Botany, H.N.B. Garhwal University, Sringar (Garhwal), India (submitted; supervisor Dr R.K. Maikhuri).

Gláucia Alves da Silva- Diversidade de fungos micorrízicos arbusculares oriundos de solos da Amazônia ocidental (Diversity of arbuscular mycorrhizal fungi isolated from Western Amazon soils). Tese em Ciência do Solo e Nutrição de Plantas (Doctoral Thesis Soil Science and Plant Nutrition) Soil Science Department/UFLA, MG. p. April 17th, 2009,

Supervisor José Oswaldo Siqueira Gohore Bi Gore Ludovic; Determination of fertility indices by the farmers: the case of the village of Goulikao, Cote d'Ivoire.
Huising E.J., (2009). Program TS2: Sustainable Land Management for Eco-efficient Agriculture in the Tropics. *Presentation at the Knowledge Sharing Week of CIAT, May 18-22, Cali, Colombia.*
Kassi Yoboua André Serge Pacôme; Growth and activities of Millsonia omodeoi (Acanthodrilidae) and Hyperiodrilus africanus (Eudrilidae) earthworms collected from Lamto (savannah land) and in forest agro-systemes of Oumé.
Koné Wowo Armand, (2009). Qualité des sols en zone de savane humide de Côte d'Ivoire : utilisation des légumineuses herbacées comme alternative pour une valorisation des terres marginales et une agriculture durable. Université d'Abobo-Adjamé (Abidjan, Côte d'Ivoire), 197 pp.
Ndri Aya Nadège Aurelie; Enzyme activities in soil from different land use types in the Oumé region (Mid_west Cote d'Ivoire: the role of earthworms.
Okoth, P and J. Huising, (2009). Arresting Hunger and Environmental Degradation in Sub-Saharan Africa: Developing a Dynamic and Globally Integrated African Soil Information Service (AfSIS). Poster presented to the CIAT Knowledge Week, May 2009, Cali, Colombia. Poster won Second Position out of the 109 Scientific posters presented to the meeting.
Okoth, P., (2009). Writing Stories to promote research work. Conservation and Sustainable Management of Below-ground Biodiversity project. CSM-BGBD project workshop on Economic Evlauation of BGBD, Kampala Uganda; December 2009.
Okoth, P., (2009). Writing Policy Briefs. CSM-BGBD project workshop on Economic Evalauation of BGBD, Kampala Uganda; December 2009.
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Okoth, P., (2009). The Digitally Integrated Africa Soil Information Service: *Concepts of Partnership in the Project. Seminar to a Stakeholders workshop in Mali, April 2009.*
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Paula Cristina Caruana Martins- Avaliação da sustentabilidade da estrutura de um Cambissolo sob diferentes usos na Amazônia ocidental (Evaluation of a Combisol structure sustainability under different uses in Western Amazon region). Dissertação em Solos e Nutrição de Plantas (MSc Thesis Soil Science and Plant Nutrition) Soil Science Department, UFLA Lavras – MG, February 27^{th}, 2009, 44p. Supervisor Dr. Moacir de Souza dias Junior.
Rodrigo Fagundes Braga- Efeitos da alteração do uso do solo na Amazônia Brasileira sobre os serviços ecológicos proporcionados pelos Scarabaeinae (Coleoptera-Scarabaeidae) [Effects of soil use change in Brazilian Amazon on ecologicla services porovided by Scarabaeinae (Coleoptera-Scarabaeidae)]. Dissertação Entomologia (MSc Thesis Applied Ecology) Entomology Department, UFLA Lavras – MG, February 27^{th}, 2009. 56 p. Supervisor Dr. Julio N.C. Louzada.
Shalini, (2009). Impact of natural and man-made disturbances on vegetation structure and density in Guptakashi range of Kedarnath Forest Divison. Indian Council of Forestry Research and Education, Dehradun (submitted: supervisor Dr R.K. Maikhuri).

Silvia Maria de Oliveira- Processos promotores de crescimento vegetal por bactérias diazotróficas simbióticas de siratro, feijão comum e caupi e de vida livre. (Plant growth promoting processes by diazotrophic bacteria symbiotic with siratro, common beans or cowpea and free-living). Dissertação em Solos e Nutrição de Plantas (MSc Thesis Soil Science and Plant Nutrition) Soil Science Department, UFLA Lavras – MG, February 27th, 2009. 66 p. Supervisor Dr. Fátima M.S. Moreira.

Zon Demeango Serge; Abundance and diversity of collembola along a gradient of land use in the Oumé area, Centre-West Côte d'Ivoire.

Technical reports (forthcoming)

Amany Bérah Cyrille. Social economical evaluation of production systems in the Goulikao village (Oumé).

Baidai Yannick Diby Armel; The role of the geophagous eartworm Dichogaster terrae nigrae (Acanthodrilidae) in changes in the level of soil compaction in a cacao orchard.

Bosso Amon, (2010). Les macro-invertébrés comme indicateurs de la qualité des sols en zones de forêt semi-décidue de Côte d'Ivoire. Mémoire de DEA, Université d'Abobo-Adjamé, 45 pp (Macro invertebrates fauna as indicators of soil quality in semi-deciduous forest zone of Oumé: the case of earthworms).

Gohore Bi Gore Ludovic; Determination of fertility indices by the farmers: the case of the village of Goulikao, Cote d'Ivoire .

Bruno Lima Soares- Eficiência simbiótica de estirpes de bactérias fixadoras de nitrogênio de diferentes procedências em caupi [*Vigna unguiculata* (L.) Walp] e sua identificação. [Symbiotic efficiency of nitrogen-fixing bacterial strains from diverse origins in cowpea [*Vigna unguiculata* (L.) Walp] and their identification) Dissertação em Solos e Nutrição de Plantas (MSc Thesis Soil Science and Plant Nutrition) Soil Science Department, UFLA Lavras – MG, February 26th, 2009, 56 p. Supervisor Dr. Fátima M. S. Moreira.

Divya Dangwal. (2009). Assessment of productivity, nutrient uptake and nitrogenase activity in three selected mountain legume crops under mixed and mono cropping. Department of Botany, H.N.B. Garhwal University, Sringar (Garhwal), India (submitted; supervisor Dr R.K. Maikhuri).

Gláucia Alves da Silva- Diversidade de fungos micorrízicos arbusculares oriundos de solos da Amazônia ocidental (Diversity of arbuscular mycorrhizal fungi isolated from Western Amazon soils). Tese em Ciência do Solo e Nutrição de Plantas (Doctoral Thesis Soil Science and Plant Nutrition) Soil Science Department/UFLA, MG. p. April 17th, 2009, Supervisor José Oswaldo Siqueira.

KASSI Yoboua André Serge Pacôme; Growth and activities of Millsonia omodeoi (Acanthodrilidae) and Hyperiodrilus africanus (Eudrilidae) earthworms collected from Lamto (savannah land) and in forest agro-systemes of Oumé.

Koné Wowo Armand, (2009). Qualité des sols en zone de savane humide de Côte d'Ivoire : utilisation des légumineuses herbacées comme alternative pour une valorisation des terres marginales et une agriculture durable. Université d'Abobo-Adjamé (Abidjan, Côte d'Ivoire), 197 pp.

Ndri Aya Nadège Aurelie; Enzyme activities in soil from different land use types in the Oumé region Mid-west Cote d'Ivoire: the role of earthworms.

II.5. Proposals funded in 2009

The budget codes and budgets for active projects in 2009 are listed below. Most of these projects are also listed in the annual report of the ISFM outcome line, apart from the Conservation and Sustainable Management of Below-ground Biodiversity, which is considered to be purely a SLM project. For the other projects listed both SLM and ISFM components can be identified. The budgets indicated are the total budgets for the projects for 2009, as we did not consider it meaningful to apply percentages corresponding to the SLM and ISFM components.

ACTIVE TSBF BUDGET CODES – 2009			
Budget Code	**Project title**	**Donor**	**Budget in 2009 (USD)**
TS01	Integration CIAT-TSBF Holdback	CIAT	90,000
TS02	CIDA-Funds to Africa	CIDA	119,000
TS10	USAID's Funds to TSBF	USAID	18,719
TS15	Bridging funds	CIAT	29,500
TS25	France CIRAD Scientist	MOFA - France	5,000
TSA63	WOTRO-More Cropping Per Dropping: Optimizing the Water and Nitrogen use efficiency $ Crop Residue Management for Water Conservation Agriculture	WOTRO	5,192
TSA67	Increasing Total Farm Productivity in Vulnerable Production Systems in Mozambique through Improved Germplasm Water and Nutrient use efficiencies	AUSTRIA	76,160
TSA83	Building adaptive capacity to cope with increasing vulnerability due to climate change	Sub-contract from ICRISAT	31,200
TSA93	Conservation and Sustainable Management of Below-ground Biodiversity	GEF	1,341,505.00
TSA97	Exploring measures to enhance the adaptive capacity of local communities to pressures of climate change	Sub-contract from UZ	36,209
TSB37	Breaking the unholy alliance of food insecurity, poverty and environmental degradation in Chitekwere EPA (Lilongwe ADD): Empowering farmers with soil, water and nutrient enhancing technologies for increased productivity	BIOFORSK	4,750
TSB47	Promoting Conservation Agriculture to Improve Land Productivity and Profitability among Smallholder Farmers in Western Kenya	KILIMO TRUST	42,951

TSB51	A Globally Integrated African Soil Information Service (AFSIS)	AGRA	372,529
TSB54	A Globally Integrated African Soil Information Service (AFSIS)	Bill & Melinda Gates Foundation	3,618,133
TSB63	AGRA - Publishing of Book by The African Network for Soil Biology and Fertility (AfNet) for Use in the Development of the Soil Health Program of The Alliance for a Green Revolution in Africa	AGRA	39,875
TSB64	Facilitating the Adoption of Conservation Agriculture by Resource –Poor Smallholder Farmers in Southern Africa.	CIMMYT	18,720
TSB73	Improving Farms Livelihoods through Multi-stakeholder Innovation Platforms for linking smallholder farmers to research, Extension and Business Development Services.	ADA	138,412
TSB76	Tropical Soil Biology Fertility Institute-Operations	IDRC	23,938
TSB84	Improving Agriculture –based Livelihoods in Central Africa through Sustainably Increased System Productivity to Enhance income, Nutrition Security and the environment -CIALCA II.	AGCD	169,739
TSB94	Improving and Strengthening Rural Community Access to Agricultural and Soil Fertility Information in Korogwe District, Tanzania	CTA	29,709
TSB96	Effects of Soil Fertility Interventions on Soil Aggregation and Organic Matter Incorporation and Stabilization: The Role of Soil Macrofauna	Sub-contract from UCLA	5,795
NSD32N	Quesungual slash and mulch agroforestry system (QSMAS): Improving crop water productivity, food security and resource quality in the sub-humid tropics	CPWF	7;250
	TOTAL		**6,224,285.7**

II.6. Staff List

TSBF Institute – Africa Staff: Time allocation to SLM program

TSBF Institute - Director		
Sanginga, Nteranya	Soil Microbiologist	50%
Senior Staff		
[1]Bationo, André	African Network Coordinator (Soil Scientist))	50%
Chianu, Jonas	Socio Economist	25%
[2]Corbeels Marc	Soil scientist, modeler	25%
Huising, Jeroen	BGBD Coordinator (GIS Scientist))	75%
Jefwa, Joyce	Microbiologist	0%
Lesueur, Didier	Microbiologist	0%
Nambiro, Elizabeth	M&E Scientist, AfSIS Project	100%
[3]Ohiokpehai, Omo	Food & Nutrition Scientist	0%
Okoth, Peter	Information Manager	100%
Pypers, Peter	Soil scientist	0%
Roing, Kristina	Agronomist	0%
Vanlauwe, Bernard	Soil Scientist	25%
Zingore Shamie	Soil Scientist	50%
Visiting Scientists		
Merckx, Roel	Katholiek University, Belgium	
Consultants		
Woomer, Paul	Soil Scientist. ISFM project	0%
Mokunywe Uzo	Economist, BGBD Project	100%
Swift, Mike	BGBD Project	100%
Research Assistants		
Kankwatsa, Peace	Research Asst, Kampala	0%
Kasareka, Bashikwabo	Research Asst, DR Congo	0%
Lodi-Lama, Jean-Paul	Agronomist, DR Congo	0%
Lunzihirwa, Julie	Research Asst, DR Congo	0%
Mukalama, John	Snr Scientific Assistant	0%
Okeyo, Jeremiah	Research Asst	25%
Rusinamhodzi, Leonard	Research Asst, Harare	25%
Sanginga, Jean-Marie	Research Asst., DR Congo	0%
[4]Waswa, Boaz	Asst Scientific Officer	25%

[1] Left during the year
[2] Left during the year
[3] Left during the year
[4] Left during the year

Mairula, Franklin	Data Analyst	
Magreta, Ruth	Research Asst, Lilongwe	50%
Mapila, Mariam A.T.J.	Research Fellow, Lilongwe	0%
Mombeyarara, Talkmore	Research Asst, Harare	50%
Technical Staff		
Chibole, Livingstone	Field Technician	0%
Dzvene, M	Field Asst, Harare	50%
Kadzere, Chengetai	Field worker, Harare	50%
Kimathi, Martin	Laboratory Assistant	25%
Mburu, Harrison	Lab Assistant-Microbiology	0%
Muthoni, Margaret	Laboratory Assistant	25%
Mwangi, Elias	Laboratory Assistant	25%
Ngului, Wilson	Laboratory Technician	25%
Nyambega, Laban	Field Technician	0%
Njenga, Francis	Laboratory Assistant	25%
Muranganwa, Francis	Field worker Harare	0%
Administrative Staff		
Agalo, Henry	Driver / Field Assistant	50%
Akuro, Elly	Driver / Field Assistant	50%
Chisvino, Stephen	Driver/OA, Harare	50%
Kareri, Alice	Administrator	50%
Kiragu, Wanjiku	Chief Operations Officer	50%
Kuya, Sebastien	Driver/Technician, DR Congo	100%
Meyo, Rosemary	Administrative Assistant	50%
Mulogoli, Caleb	Finance Officer	50%
Mutende, Oscar	Finance Assistant	50%
Mary Nderitu	Finance Assistant	50%
Ngwira, Evelyn	Accounts Asst, Lilongwe	50%
Nomsa Nhaoinesu	Admin Asst., Harare	50%
Nyamhingura, Isabella	Admin. Asst, Harare	50%
Odongo, Jacqueline	Administrative Asst.	50%
Ogola, Juliet	Snr Administrative Asst.	50%
Oruta, Annah	Project Administrator	50%
Sambo, Margaret	Admininistrative Asst	50%

TSBF Institute – Latin America Staff

Patrick Lavelle	Soil Ecology	100%
Visiting Researcher		
Castro, Aracely	SLM	50%
Secretary		
Gómez, Julia	Secretary	12%

II.7. SUMMARY BUDGET

SOURCE	AMOUNT (US$)	PROPORTION (%)
TSBF		
Unrestricted Core	257,219	4%
Restricted Core	0	0
Sub-total Core	**257,219**	**4%**
Restricted		
Special projects	5,540,880	89%
Sub Sahara Africa Challenge Program	4,750	0%
Water and Food Challenge Program	0	0
Sub Total Restricted	**5,545,630**	**89%**
Direct Expenditures	**5,802,848**	**93%**
Non Research Cost	421437.4	7%
Total Expenditures	**6,224,285.70**	**100%**

III. Progress against output targets 2009 – 2011

III.1. Output 1 - Biophysical processes that underlie soil health and drivers of soil degradation understood, principles for restoring soil health in agro-ecoystem defined

Outputs (Intended users)	Outcome (Impact)
Description: Biophysical processes of soil degradation and principles that underlie soil health; Root and proximate causes of soil degradation; Principles and concepts for restoring soil biological quality and soil health defined. Intended users: CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia.	Outcome: Understanding of soil processes important to provide soil ecosystem services informs the development of technologies and management options (see Output 2). Impact: Standard methods and indicators help assessment of soil health status in uniform and consistent manner and allows for identification of soil health problem and creates awareness of severity of the problem and generates action preparedness among stakeholders.

Output 1: Concepts, principles and processes:
The former output on the processes and principles underlying the functioning of ISFM has been integrated in the SLM research programme, with a gradual shift of emphasis on processes at landscape level, land use patterns and associated land degradation, sustainable land use mosaics and sustainable production landscapes. However, the soil based delivery processes for provision of ecosystem services and the role of soil biota in regulating these processes will remain an important component of the research. For example the role of earthworms and other soil biota in the soil aggregate formation process and hence the effect on soil fertility and improved soil hydraulic properties is part of the processes investigated. The activities in relation to this output are concentrated around the inventory of soil properties (chemical, physical, soil organic matter and soil biological) and based on this the diagnostic of soil health related problems and the development and testing of methods for the assessment of the soil resource base status. Special attention will be devoted to methods for the inventory of BGBD and the assessment of soil biological quality apart from the soil chemical, physical and SOM quality aspects.

The output target for 2009, *viz* practical methods for rapid assessment and monitoring of the soil resource bases status in relation to nutrients, organic matter and soil biota is split into two; one target concerning the assessment of the soil nutrient, SOM and soil structural characteristics and one for methods for inventory of BGBD. The latter is considered to have been achieved, and will not be a specific target for the coming years, though methods will further develop.

The processes that underlie soil erosion and chemical degradations and the direct causes or drivers of these processes are fairly well understood. This may be less so in case of soil physical and biological degradation. Moreover, relatively little is known how to describe land degradation at a landscape level and what the consequences are for the provision of ecosystem goods and services. The CSM-BGBD project, the AMAZ project and the AfSIS project explicitly address the landscape level and progress is reported here. These projects also work on indicators to monitor soil and land quality and this work is also reported under output 1.

Further to this, efforts in modelling of these soil processes, e.g. in relation to soil carbon, crop modelling and modelling of the farming system, are also reported here as all these models will provide the decisions tools to support decision in sustainable land management.

Major research questions are:

→ *Which approach and methods should be used for the inventory of below-ground biodiversity?*

→ *Which indicators can be used for the assessment of soil quality (soil chemical, physical, SOM and biological quality)?*

→ *What are the tools and approaches to diagnose soil health problems?*

→ *What is the role of soil biota in soil based processes that support the provision of ecosystem services and is there a way to assess this and what is the importance of soil biodiversity?*

→ *What are effective biological technologies or intervention options to enhance soil biodiversity and soil health?*

Output 1. Biophysical processes and soil health
Output Target 2009: Practical methods for rapid assessment and monitoring of the soil resource base status in relation to soil nutrients, organic matter, aggregation and soil structure.

Output 1 The emphasis of this output target is on soil ecological processes that maintain soil health and consequently also underlying soil and land degradation, besides the methods for rapid assessment and monitoring of soil health status. Apart from some technical publication we present here some general descriptions of projects that will provide a major contribution to this output target in the coming years, though they likewise will contribute to other outputs specified.

WORK IN PROGRESS

Reconstruction of eco efficient landscapes in deforested Amazonia, Lessons from the AMAZ project.

P. Lavelle, Arnauld de Sartre, X. Gond, V. Decaëns, Th. Martins, M. Feijoo, A. Grimaldi, M. Hubert, B. Doledec, S. Veiga, I. Ramirez, B. Oszwald, J. and the AMAZ team

The future of Amazonia forest may well depend on the way the 30% already deforested land is used as much as on direct protection efforts. We still have no idea of the comparative eco efficiency of different landscapes built in these areas and less so of how to build landscapes that will meet the challenges of human development and global change in the next two decades.

The AMAZ project

The objective of the AMAZ project was to identify the socio economic determinants of the production of goods and soil borne ecosystem services, via landscapes constructed by people and the biodiversity that inhabits these landscapes. Over 2000 variables have been measured to evaluate the socio economic environment, landscape metrics, biodiversity, productions and ecosystem services (soil quality indicators, C sequestration, hydric services and soil chemical fertility).

These variables were measured in a sampling protocol that provided fully compatible sets of quantitative or semi quantitative data that allowed comparisons based on multiple coinertia analysis. In each of six landscape windows with different ages of deforestation and different colonization histories, from Para (Eastern Brazil) and Caqueta (Colombian Andean piedmont), Socio economic parameters and landscapes were described in 50 farms. In a set of 9 farms representative of each window, biodiversity of 8 groups (plants, birds, Drosophilidae, Saturnidae, earthworms, termites, ants and soil macrofauna), agro sylvo pastoral productions and soil borne ecosystem services (C sequestration, hydric functions, chemical fertility) were measured in 5 points representative of each farm.

Socioeconomic, landscape, biodiversity, productions and ecosystem services significantly covary

Multiple coinertia analysis showed significant covariations among the different sets of data. Groups of people belonging to a given socioeconomic categories therefore build specific types of landscapes that host different biodiversities, have specific productions and provide different amounts of ecosystem services. Further analyzes will detail these results and describe the landscapes created by different groups of farmers belonging to different socioeconomic types, biodiversity that inhabits these landscapes, productions and soil ecosystem services.

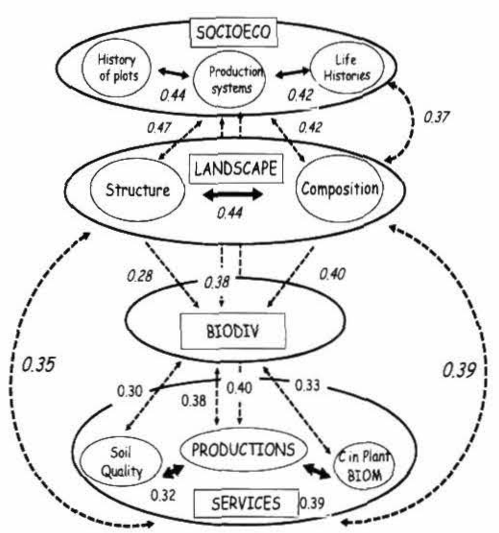

Figure 3: Statistical relationships among socioeconomic, landscape, biodiversity, productions and ecosystem services data sets (Brazilian landscape windows) (*numbers indicate values of RV coefficients of covariation among tables of data; all values indicated here are significant at p<0.05)*

Ecoefficiency of farms and landscapes

A major outcome of the project is the measurement of ecoefficiency at farm and landscape levels. It is well known that some production systems are more efficient at producing commodities and generating incomes than others, while impacts on the environment also vary. We propose a formula to assess this eco efficiency and thus compare the impact of production systems produced by different types of socioeconomic groups on landscapes, productions and environment parameters.

Eco efficiency: $E_f = P_e * S_q * B_d$

with E_f= income $ /ha used/labour UTE unit; S_q: soil quality (GISQ index; Velasquez et al., 2007) 0.1 to 1.0; B_d: Biodiversity index (0.1 to 1.0) calculated in a similar way. This formula was used to compare ecoefficiency of farms from the three different dominant production systems in Colombia

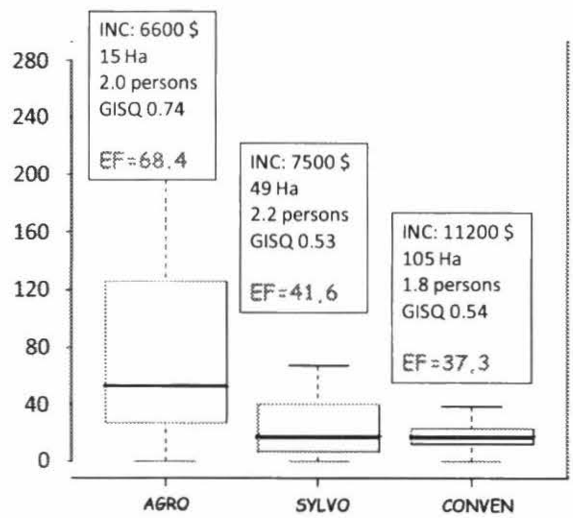

Figure 4: Ecoefficiency of farms in different dominant production systems in Caqueta (Colombia) AMAZ sites. Solid bar is median, box comprises 25% percentiles, dashed lines indicate mini and maxi values

The next step: reconstructing eco efficient landscapes in Amazonia

The Amaz project showed the importance of landscape, a construction of human communities that may have very contrasted performances in terms of productions, conservation of biodiversity and provision of ecosystem services. AMAZ provides a methodology for diagnostic of the different elements of eco efficiency and a way to individually assess farms and landscapes.

The methodological and conceptual progress thus made allows envisaging a next step that is the reconstruction of eco efficient landscapes. After a diagnostic phase derived from the AMAZ project, although much reduced, a model based on data set created during the diagnostic is built. This model serves as a tool in a participative exercise of optimization of the landscape that will identify the landscape components and composition of the mosaic that best allows production of goods and ecosystem services. The next step consists in reconstructing the landscape and organizing markets for the new products thus made available. During the whole process, narrow link is maintained with policy makers in order to create synergies between the project considered as a full scale experimental situation and developing policies to create incentives and/or markets for ecosystem services.

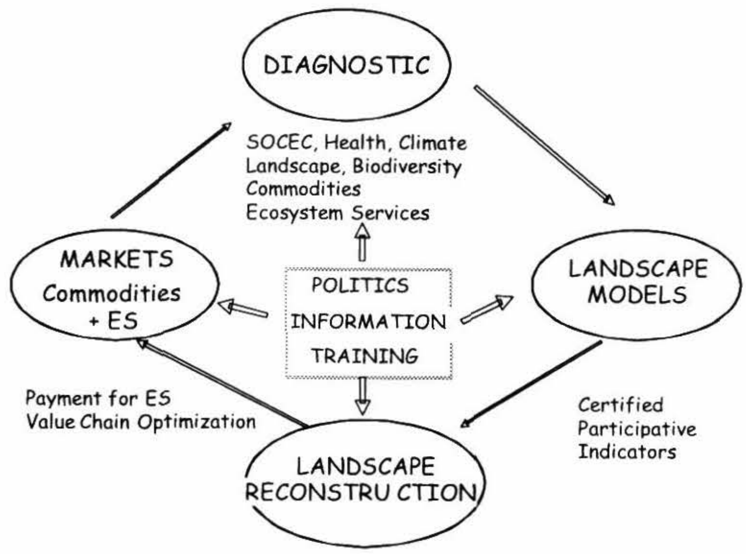

Figure 5: Conceptual framework for projects on landscape reshaping (Amazonia 2030 sub. to Fondo Amazonia)

COMPLETED WORK

Cast production and NIR spectral signatures of Aporrectodea caliginosa fed soil with different amounts of half-decomposed Populus nigra litter

(2009) Biology and fertility of soils, 45 (8): 839-844

Zhang[1], C., Langlest[2,5], R., Velasquez[4,5], E., Pando[2], A., Brunet[6], D., Dai[1], J. and Lavelle[3], P.

[1]College of Natural Resources and Environment, South China Agricultural University; [2]UMR BIOEMCO, IRD, France; [3]UMR BIOEMCO, IRD, TSBF-CIAT, Colombia; [4]Universidad Nacional de Colombia Palmira, Colombia, [5]TSBF Institute of CIAT, Cali, Colombia [6]UR SeqBop IRD/MOST, France

Abstract: Sub-adult individuals of Aporrectodea caliginosa were incubated for 16 weeks under laboratory cultures in a soil treated with 0%, 10% or 50% of a Populus nigra half-decomposed leaves, respectively. Growth was maximum in the 50% organic matter treatment and cocoon production occurred. Average soil ingestion rates decreased from 1.56 g/g(-1) fresh weight of worm per day(-1) in control soil to 1.17 and 0.5 g, respectively, in treatments with 10% and 50% half-decomposed litter. Surface casts never comprised more than 10% of total cast production. Near-infrared spectrometry (NIRS)signatures of digested and non-ingested soil significantly differed and showed a rather constant effect of digestion, independent of the organic matter content ($p < 0.01$). These results confirm the value of NIRS

spectral signatures as indicators of the origin of soil aggregates and biological processes involved in soil aggregation.

Digital Soil Map of the World *(2009) Science, v. 325: 680-681*

Sanchez[1], P., Ahamed[1], S., Carré[2], F., Hartemink[3], A.E., Hempel[4], J., Huising[5], J., Lagacherie[6], McBratney[7], P., [8]McKenzie, A.B., Mendonça-Santos[9], N.J., Minasny[7], B., Montanarella[2], L. Okoth[5], P., Palm[1], C.A., Sachs[1], J.D., Shepherd[10], K.D., Vagen[10], T., Vanlauwe[5], B., Walsh[5], M.G., Winowiecki[5], L.A. and Zhang[11], G.
[1]Earth Institute at Columbia University, [2]European Commission, Joint Research Centre, [3]ISRIC World Soil Information, [4]USDA-NRCS National Geospatial Development Center, [5]CIAT-TSBF c/o ICRAF [6]INRA –IRD (LISAH), [7]Faculty of Agriculture, Fodd & Natural Resources the University of Sydney, [8]CSIRO Land and Water, Australia [9]Embraoa, National Center of Soil Research – Embrapa SolosRua Jardim Botânico, [10]World Agroforestry Centre (ICRAF), [11]Institute of Soil Science, Chinese Academy of Sciences, China

Abstract: This paper introduces the new initiative a digital soil map of the world. It makes the argument of the importance of soil information for management of ecosystems and climate regulation. The paper reviews past efforts and past generation of global soil maps and its shortcomings that in general relate to a too low resolution to be practical for land management decisions and the lack of quantitative information on soil properties that are indicative of the degree of soil degradations. The approach to the digital global soil map consists of three components: digital soil mapping, soil management recommendation and serving the end user. The three main steps in digital soil mapping are described as 1 data input and assembling and calibrating spatially contiguous covariates from available data, with the covariates reflecting state factors of soil formation (climate information, land cover and range of digital terrain variables and geological parameters relating to soil parent material. Step 2 involves the estimation of soil properties, expressed as probabilities of occurrence and step three is the use of spatially inferred soil properties to predict more difficult to measure soil functions such as available soil water storage, carbon density and phosphorous fixation, using pedo-transfer functions. Data from georeferenced field trials are use to diagnose soil health problems and to formulate soil management recommendations. In step 4 also co-variates are used and these include socio-economic parameters. These socio-economic covariates address additional state factors of soil formation. The end user will be served by data and information products relating to soil functional properties, soil management recommendations that will form the baseline against changes can be monitored and evaluated over time. The products will be tailored to specific needs of the end user.

A new information system for managing sub-Saharan Africa's soils: why and how.

Walsh[1], M., Ahamed[2], S., Hartemink[3], A.E., Huising[1], J., Okoth[1], P., Palm[2], C.A., Sanchez[2], P., Sanginga[1], N., Shepherd[4], K.D., Vagen[4], T. and Winowiecki[4], L.A.
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Soil information for Africa: Why?

Almost 70 years ago Hans Jenny outlined the components of a dynamical systems framework of the state factors of soil formation. The factors include climate, organisms, topography, parent material and time as well as more locally contingent variables such as fires, various forms of pollution, tillage, fertilizer applications, and livestock grazing, among others.

As predicted by Jenny, human activities have dramatically altered the state of climate, organisms and the contingent factors on a global scale, and the rates of human-driven change processes in these are expected to accelerate over the next 100 years, particularly in Africa2. People depend on soils for a wide range of ecosystem services. For example, soils are a key resource in the production of food, forage, fuel and fiber. Soils store and cycle water from rainfall and irrigation and filter toxic substances through clay sorption and precipitation processes that determine surface and ground water quality. Soil organisms decompose organic materials, cycle nutrients and regulate gas fluxes to and from the atmosphere.
As human populations have grown, there has been a strong tendency to trade off increases in the demand for provisioning services (e.g., for food and other commodities) for regulating (e.g., nutrient, greenhouse gas and hydrological cycling) and supporting services (e.g., biodiversity) 3. In many places in sub-Saharan Africa (SSA), positive feedback dynamics between growing populations, land cover and climate change have led to a rapid loss in the capacity of soils to deliver essential ecosystem services. In some areas it has initiated catastrophic ecological regime shifts4, with prominent examples including the Lake Victoria Basin of East Africa, the Sahelian drylands, and the humid forests of Madagascar. These highly undesirable changes are not easily reversible and are major, though largely hidden, costs of development, which challenge the prospects of a better future for Africans, trapping them into poverty, and leading to increased conflicts over land.

Moreover, SSA's population is likely to double over the next 25-30 years, rising to an expected ~1.75 billion people by the year 2050, when it will represent 20% of the human population of our planet5. This new population will not only demand more services from soils and ecosystems as a whole, but its per capita demand for such services must also increase if human development and poverty indices are to improve.
It is therefore striking that as mankind is successfully exploring, mapping, and monitoring other planets of our solar system, we know very little about the condition and trend of soils in Africa. The spatial and thematic coverage of soil information in Africa is highly uneven and most soil observations are not adequately georeferenced. In many African countries, soil data and maps have also vastly exceeded their expiration date, as soil properties have changed since the 1950's to 70's, when most soil surveys were conducted. Thus wherever data do exist, they are typically inadequate for planning and evaluating current land-management policy and practice.

For example, questions about how and where to manage soil water retention, salinity, acidity, accelerated erosion, carbon storage, fertilizer responses, and many others of equal importance, are currently impossible to answer in any kind of geographically coherent manner or with some acceptable level of uncertainty.

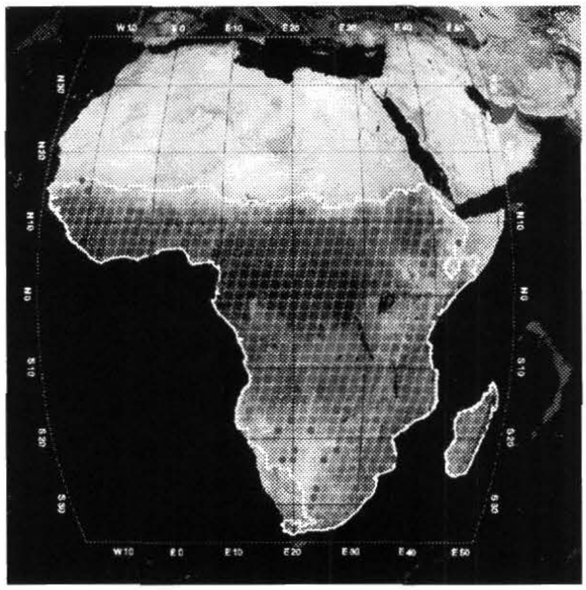

Figure 6: Geographic coverage of the Africa Soil Information Service.

The area delineated in white excludes the true deserts of Africa. The grey grid represents (663) potential sentinel landscape locations in the Landsat World Reference System (WRS2). Red dots represent the centroid locations of 60 sentinel landscapes that will be surveyed by AfSIS field teams. Also see www.africasoils.net for more detail.

Soil information for Africa: How?

Over the next four years, the newly formed Africa Soil Information Service (AfSIS), a collaborative project between GlobalSoilMap.net and scientists led by the Tropical Soil Biology and Fertility Institute (TSBF) of the International Center for Tropical Agriculture (CIAT), based in Nairobi, will attempt to narrow sub-Saharan Africa's soil information gap and provide a consistent baseline for monitoring soil ecosystem services.

The AfSIS project area includes ~17.5 million km2 of continental SSA and ~0.6 million km2 of Madagascar, an area that encompass >90% of Africa's human population living in 42 countries. The project area excludes the hot and cold desert regions based on the recently revised Köppen-Geiger climate classification7, as well as the non-desert areas of Northern Africa, small island nations, protectorates and national territories **(Figure 6)**. AfSIS ground survey teams will sample this vast area using a, spatially stratified, random sampling approach consisting of 60 sentinel landscapes (100 km2 each), that are representative of the variability in climate, topography and vegetation of the project area. Twenty-one of the 60 landscapes fall within biodiversity hotspots as designated by Conservation International (also see www.africasoils.net).

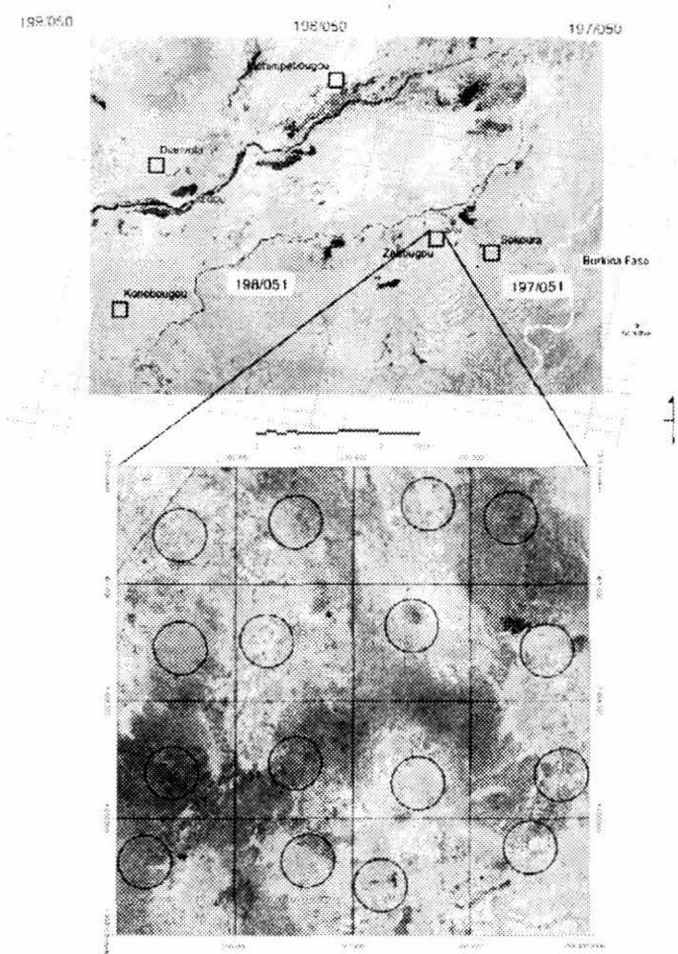

Figure 7: Locations of 5 sentinel landscapes in Segou, Mali.

The top picture is a radiometrically corrected mosaic of 4 Landsat ETM+ satellite images from 2002 (with Landsat WRS2 path/row coordinate overlay). Sentinel landscape locations are shown in black outline. The bottom picture is a QuickBird satellite image of the Zebougou sentinel site. The black circles designate 1 km2 sampling clusters in which all ground sampling activities are conducted.

The main advantage of this new data collection effort lies in its randomized, hierarchical sampling approach **(Figure 7)** that replicates soil and other biophysical (e.g. land cover / use) measurements at different spatial scales, linking consistent, georeferenced ground observations to laboratory measurements, agronomic field trials and remote sensing data . Ground surveys of the AfSIS sentinel landscapes will provide ~9,600 new soil profile observations and more than 38,000 soil samples. Satellite broadcast corrected, georeferencing and sentinel landscape documentation with digital photography will further ensure that sampling locations can be revisited at later points in time to quantify where specific changes occurred and which environmental and human-made factors caused these.

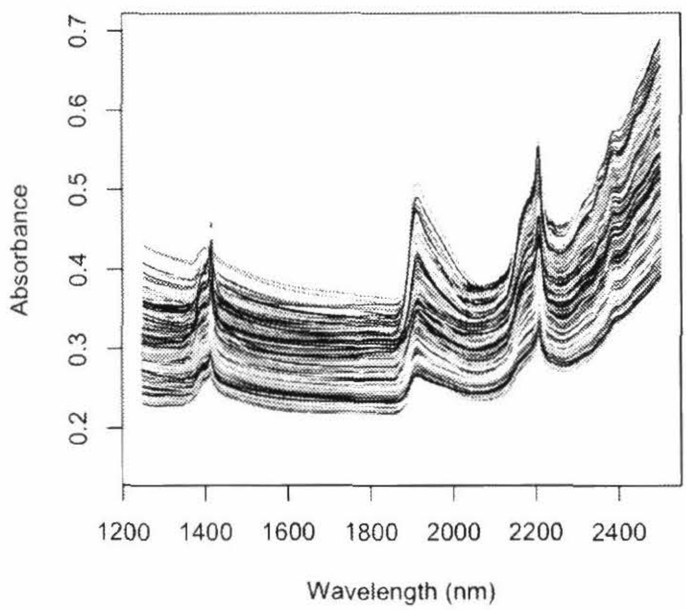

Figure 8: NIR-Spectral library of georeferenced and matched topsoil (0-20 cm) and subsoil (20-50 cm) samples from 800 sampling locations in Segou, Mali. Grey lines indicate topsoils, black lines indicate subsoils.

It would be cost and time prohibitive to analyze these new soil samples for e.g., carbon and nutrient content, texture, mineralogy, water holding capacity and other potentially important soil properties, using standard laboratory techniques. Instead, a key innovation of AfSIS is to use near **(Figure 8)** and mid-infrared, X-ray fluorescence, X-ray diffraction spectroscopy and laser diffraction for soil analyses. One of the main strengths of using these spectroscopic techniques for predicting soil properties viv-a-vis the traditional laboratory based techniques lies in the application of a double-sampling procedure that greatly reduces the cost and time of laboratory analyses, while improving the analytical precision of the resulting landscape level estimates 8. In double sampling only a subset of recovered samples (normally 10-20% of the complete data-set) is characterized with conventional laboratory analyses and the properties of the remaining samples are predicted from the spectral properties **(Figure 9).** The new data collections will also be supported with data from what is currently the most comprehensive international soil profile database for Africa (see ISRIC WISE v. 3.1 at www.isric.org), which contains information on 4,173 African soil profiles 9. AfSIS will add to this resource by digitizing additional soil profile "legacy data" where these can be retrieved from African soil survey and research organizations, georeferenced and subjected to GlobalSoilMap.net data quality standards and control criteria 9. Substantial effort will be devoted to assembling and harmonizing satellite image time series and digital terrain models for SSA. These base maps will be used as spatial covariates for digital soil mapping, but can also be used for other mapping and modeling purposes. For example, AfSIS will use MODIS, Landsat, ASTER and Quickbird images and SRTM terrain models for soil mapping, land cover change detection and estimation of landscape carbon stocks. By linking legacy, field and laboratory data to remote sensing information, digital terrain models, and other existing environmental covariates, AfSIS will thus be able to provide a unique resource for producing a new generation of soil, vegetation and land-cover maps as well as wide range of statistical products for SSA.

The digital soil maps will be accompanied by another key output of AfSIS – a spatial database containing the results of agronomic management experiments that have been carried out across Africa's diverse agro-ecological zones. On the basis of this data, crop simulation and statistical models will be used to predict the performance of different sets of suggested interventions, including the use of integrated soil fertility management (ISFM) recommendations. ISFM is the application of soil fertility management practices, and the knowledge to adapt these to local conditions that optimize fertilizer and organic resource use efficiency and crop productivity. Further field testing of the ISFM approach in carefully selected sentinel landscapes will greatly increase our ability to predict agronomic responses to management interventions.

All AfSIS data will be held in a secure cyber infrastructure that will be freely disseminated through web-portals such as www.africasoils.net, www.globalsoilmap.net and via other platforms like Google Earth and Microsoft Virtual Earth. The system will feature online upload capability, so that legacy datasets such as soil profile observations and results of management experiments can be digitized remotely. The project will also explore the use of low-cost, mobile storage devices that can deliver data, models and interfaces to users who do not have access to the internet.

The hold-out validation was conducted by leaving out an entire landscape, developing a spectral calibration model, and then predicting the SOC values of the hold-out landscape using a Multilevel Principal Components Regression approach. Also **(see Figure 7)** for landscape locations.

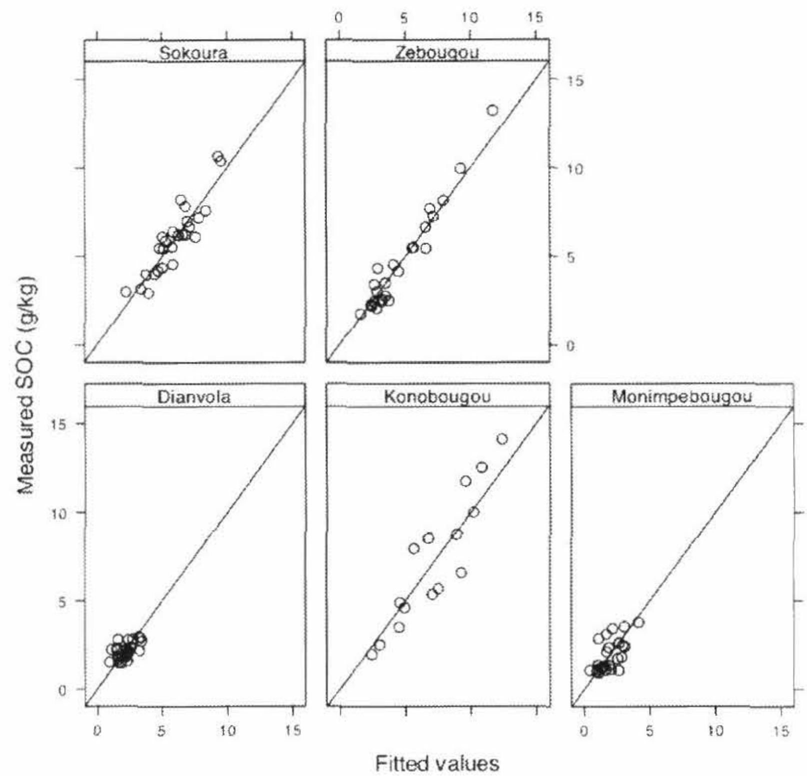

Figure 9: Example topsoil (0-20 cm) NIR spectral holdout validation plots for organic carbon for five sentinel landscapes in Segou, Mali.

In many ways similar to the US National Science Foundation's Long Term Ecological Research (LTER) sites, the AfSIS sentinel landscape network will serve as the geographical core of what we anticipate will be a long-term ecological observatory for SSA, in which changes in soils, ecosystems and the services they provide can be explored and documented over time. As the term "sentinel" suggests, the AfSIS landscapes are intended stand guard and warn of threats to SSA's natural resource base. We also hope that once AfSIS methods products are evaluated and disseminated, that African governments and research organizations will establish many more sentinel landscapes to provide an increasingly detailed assessment of Africa's soils and ecosystems over time, that result in local innovations which lead to sustainable improvements in soil and ecosystem services.

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Output 1. Biophysical processes and soil health
Output Targets for 2009: Standard methods for the inventory of BGBD documented (handbook published).

COMPLETED WORK

The handbook of Tropical Soil Biology: Sampling and characterization of Below-ground Biodiversity *(Eds.)*

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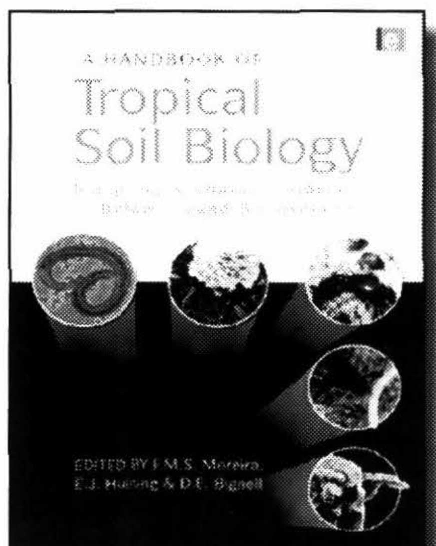

Society has long known of its dependence on soils, but only recently has considered soils as having a biologically active component. By any measure, soils worldwide are in trouble, and there is a critical and immediate need to apply knowledge about the role of below-ground biodiversity in sustaining soils. This book unquestionably provides the best and most up-to-date effort to document how to assess soil biodiversity in ecosystems that are being rapidly altered by land-use changes. Intensification is necessary to ensure global food supplies, but as intensification occurs the biological regulation of soil is altered and often substituted by fertilizers and mechanical tillage. This, in turn, frequently results in reduction of soil biodiversity and presents a challenge. Ecologists have long debated the possible importance of soil biotic diversity, citing carbon sequestration in soils, reduction of greenhouse gas emissions, maintenance of soil physical structure and water retention capacity, nutrient provision to plants and control of plant pathogens as specific contributions of soil organisms to soil fertility. The relationship between species diversity and functional diversity of the soil biota remains uncertain, but is the subject of investigation at all levels from the laboratory to the landscape.
This book is intended to provide internationally accepted standard methods for the inventory of below-ground communities and characterization of land use in the humid tropics
The explicit aim is a practical one: to provide a definitive tool to establish a base-line and then to document the loss of soil biodiversity associated with deforestation and the process of agricultural intensification at forest margins.

The book contains the following chapters:

The inventory of soil biological diversity: concepts and general guidelines, by Swift, M.J., Bignell, D.E., Moreira F.M.S. and Huising, E.J.

Sampling Strategy and Design to Evaluate Below-ground Biodiversity, by Huising, E.J., Coe, R., Cares, J.E., Louzada, J.N., Zanetti, R., Moreira, F.M.S., Susilo, F.X., Konaté, S., Noordwijk, M., and Huang, S.P.
Macrofauna, by Bignell, D.E., Constantino, R., Csuzdi, C., Karyanto, A., Konaté, S., Louzada, J.N., Susilo, F.X., Tondoh, J.E., and Zanetti, R.
Soil Collembola, Acari and Other Mesofauna – The Berlese Method, by Karyanto, A., Rahmadi, C., Franklin, E., Susilo, F.X., and Wellington de Morais, J.
Soil Nematodes, by Cares, J.E., and Huang, S.P.
Nitrogen-fixing Leguminosae-nodulating Bacteria, by Moreira, F.M.S.
Arbuscular Mycorrhizal Fungi (AMF), by Bagyaraj, J.D., and Sturmer, S.L.
Saprothytic and Plant Pathogenic Soil Fungi, by Pfenning, L.H., and Abreu, L.M.
Sampling, Conserving and Identifying Fruit Flies, by Silva, N.M.
Entomophatogenic Fungi and Nematodes, by Alcides Moino Jr. and Ricardo Sousa Cavalcanti.
Description and classification of land use at sampling locations for the inventory of below-ground biodiversity, by Huising, E.J.

Output 1. Biophysical processes and soil health
Output Target 2009: BGBD assessed in 11 benchmark sites across the Tropics and loss of BGBD as result of land use intensification determined; Assessed of soil health status in agric prod. landscapes of major agro-ecological impact zones.

COMPLETED WORK

Below-Ground Biodiversity in Sierra de Santa Marta, Los Tuxtlas, Veracruz, Mexico *(2010) (Eds)*

Barois[1], I., Huising[2], E.J., Okoth[2], P., Trejo[3], D., and Santos, M.
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Abstract: Within the frame of the project "Conservation and Sustainable Management of Below Ground Biodiversity" funded by GEF, supported by the United Nations. Environmental Programme (UNEP) and executed by CIAT-TSBF and the Instituto de Ecologia A.C. with the participation of 45 persons and 12 institutions of Mexico, Inventories of 8 groups of soil organism were carried out in La sierra de Santa Marta in los Tuxtlas: from microorganism to macrofauna: rhizobial bacteria, root pathogenic and arbuscular mycorrhizal fungi, nematodes and macrofauna (size>2mm) and particularly ants, beetles and earthworms. The chapters of the book present a detailed description of the benchmark site and the socio-economic condition prevailing in the area, the methodologies for field sampling and extraction of the organisms, the identification and taxonomic classification, the analyses of abundance and diversity of the 8 groups.

Distribution of soil organisms in diverse tropical ecosystems: The impact of land use change on abundance, richness and diversity.

Okoth[1], P., Huising[1], J., Mung'atu[2], J. and Ichami[1], S.
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Abstract: It is argued that soil organisms and their individual functions provide an important resource for the sustainable management of agricultural productivity in addition to other ecosystem services. We investigated four macro-fauna groups i.e., ants (Hymenoptera: Formicidae); beetles (Coleoptera); earthworm communities; termite communities (Isoptera); and one fungal group (arbuscular mycorrhizal fungi) across land use intensity gradients in selected benchmark areas in Brazil, Cote d'Ivoire, India, Indonesia, Kenya, Mexico, and Uganda. Sampling was carried out within 'sampling windows' in each benchmark area to capture occurring land use kinds and systems.

Earthworms were collected from the field using monoliths at the end of the rainy season where earthworms are known to be more active. Termites, ants and beetles were studied using soil monoliths measuring 25 x 25 x 30 cm. A modified ALL (Ant leaf litters) protocol based on a Winkler and Pitfall trap collecting method was used to collect ants. Beetles were extracted from litter using the Winkler. Arbuscular mycorrhizal fungi (AMF) were extracted from 12 points using augers around two concentric rings measuring 3 and 6 meter radius. Soil core samples were taken up the depth of 20 cm using a soil corer of 5 cm diameter and 20 cm long. Eight different points within the 6m radius and 4 points in the 3 m radius were cored and the soil bulked together.

Statistical analyses were used to evaluate the influence of land use intensity and the geographic location of benchmark sites on the biodiversity of the soil fauna. The analyses were based on biological diversity indicators; i.e., species abundance, species richness, and species diversity using the Shannon-Wiener Index and the evenness of the species distribution across land use kinds. The highest richness was encountered in agroforestry systems where the arbuscular mycorrhizal fungi (AMF) recorded 17 species.

Nitrogen-fixing bacteria communities occurring in soils under different uses in the Western Amazon Region as indicated by nodulation of siratro (Macroptilium atropurpureum) *(2009) Plant and Soil, 319: 127-145*

Lima[1], A.S., Nóbrega[2], R.S.A., Barberi[3], A., Silva[4], K., Ferreira[4], D.F., and Moreira[4], F.M.
[1]Federal University of Campina Grande; [2]Federal University do Piaui; [3]National Institute of Agrarian Reform; [4]Federal University of Lavras, Brazil

Abstract: Understanding native communities is a crucial step for the management of biological nitrogen fixation, since they may be either a source of efficient strains or a limiting factor when efficient strains need to be introduced. This work aimed to evaluate the density, diversity and efficiency of Leguminosae nodulating bacterial (LNB) communities and their component strains in soils under various land use systems (LUSs): pristine forest, agriculture, pasture, agroforestry, young secondary forest, and old secondary forest,. The LNB communities were trapped from these soils by using the promiscuous host siratro under controlled conditions. We also studied their relationships with physical and chemical attributes of the soil. Agroforestry and agriculture soil samples induced the highest number of

nodules in siratro, while forest soil samples induced the lowest number of nodules. No relationship was found between LNB and Leguminosae species diversity in the LUSs. The soil chemical variables that were most related to differences in nodule number and shoot dry matter weight of plants inoculated with soil suspensions of the LUSs were, respectively: Ca^{2+}, Mg^{2+}, base saturation, exchangeable bases and Cu^{2+}; and pH, cation exchange capacity, B, Cu^{2+} and clay. Although, LNB communities from all LUSs were efficient under controlled and similar conditions, they were found to be composed of strains with variable efficiency: inefficient, efficient, highly efficient and superior efficiency. Efficient strains occurred at the highest frequency in all LUSs. The isolated strains presented similar and new sequences that were phylogenetically related to well known LNB genera in α-and β-Proteobacteria. Unusual genera in these branches, as well as in other branches, which are probably endophytic bacteria, were also isolated from nodules. These data support siratro as a useful trap species to study the LNB biodiversity of diverse ecosystems in tropical soils. The fact that the highest diversity and nodulation were seen in managed systems such as agriculture and agroforestry suggests a high resilience of LNB communities to changes in land use after deforestation in a region where large forest areas are still preserved and can be a source of propagules.

Changes in land use alter the structure of bacterial communities in Western Amazon soils *(2009) The ISME Journal 1–8. Available on line*

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Abstract: Here we show how agricultural practices by indigenous peoples as well as forest recovery relate to the structure and composition of Amazon soil bacterial communities. Soil samples were collected in different land use systems and bacterial community composition and diversity were explored by T-RFLP, cloning and sequencing, and data were analyzed with multivariate techniques. The main differences in bacterial community structure were related to changes in the soil attributes that, in turn, were correlated to land use. Community structure changed significantly along gradients of base saturation, [Al3þ] and pH. The relationship with soil attributes accounted for about 31% of the variation of the studied communities. Clear differences were observed in community composition as shown by the differential distribution of Proteobacteria, Bacteroidetes, Firmicutes, Acidobacteria and Actinobacteria. Similarity between primary and secondary forest communities indicates the recovery of bacterial community structure during succession. Pasture and crop soil communities were among the most diverse, showing that these land use types did not deplete bacterial diversity under the conditions found in our sites.

Occurrence and diversity of arbuscular mycorrhizal fungi in trap cultures from soils under different land use systems in the Amazon, Brazil *(2009)*

Brazilian Journal of Microbiology, v. 40, 111-121

Leal[1], P.L., Stürmer[2], S.L. and Siqueira[3], J.O.
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Abstract: The aim of this work was to evaluate the occurrence of arbuscular mycorrhizal fungi (AMF) species diversity in soil samples from the Amazon region under distinct land use systems (Forest, Old Secondary Forest, Young Secondary Forest, Agroforestry systems, Crops and Pasture) using two distinct trap cultures. Traps established using *Sorghum sudanense* and *Vigna unguiculata* (at Universidade Regional de Blumenau - FURB) and *Brachiaria decumbens* and *Neonotonia wightii* (at Universidade Federal de Lavras - UFLA) were grown for 150 days in greenhouse conditions, when spore density and species identification were evaluated. A great variation on species richness was detected in several samples, regardless of the land use systems from where samples were obtained. A total number of 24 AMF species were recovered using both methods of trap cultures, with FURB's traps yielding higher number of species. *Acaulospora delicata, A. foveata, Entrophospora colombiana* and two undescribed *Glomus* species were the most abundant and frequent species recovered from the traps. Number of species decreased in each genus according to this order: *Acaulospora, Glomus, Entrophospora, Gigaspora, Archaeospora, Scutellospora* and *Paraglomus*. Spore numbers were higher in Young Secondary Forest and Pastures. Our study demonstrated that AMF have a widespread occurrence in all land use systems in Amazon and they sporulate more abundantly in trap cultures from land uses under interference than in the pristine Forest ecosystem.

Diversity of nematode destroying fungi in Taita Taveta, Kenya *(2009)*

Fungal Ecology

Wachira[1], P., Mibey[1], R., Okoth[1], S., Kimenju[1], J. and Kiarie[1], J.
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Abstract The diversity of nematode destroying fungi in Taita Taveta, Wundanyi division, Coast Province, Kenya, was investigated between May 2006 and December 2007 aiming at harnessing their potential in the biological control of plant parasitic nematodes in the area. Given that the intensity of land cultivation is continually increasing in the study area, it is prudent to document the status of the nematode destroying fungi before the remaining forest habitats are ultimately disrupted. Soil samples were collected from forest, maize/ bean, napier grass, shrub and vegetable fields, which represented the main land use types in the study area. The soil sprinkle technique method was used to isolate the nematode destroying fungi from the soil. The fungi were identified to species level. Eighty-five isolates, distributed in eight genera and 14 taxa were identified as nematode destroying fungi. The species identified were Arthrobotrys dactyloides, Arthrobotrys oligospora, Arthrobotrys superba, Acrostalagamus obovatus, Dactyllela lobata, Harposporium aungulilae, Harposporium liltiputanum, Harposporium spp, Haptoglosa heterospora, Monacrosporium asterospernum, Monacrosporium cianopagum, Myzocytium, spp, Nematoctonus georgenious and Nematoctonus leptosporus. Vegetable land use had the highest diversity of nematode destroying fungi. The results show that the study area is rich in nematode destroying fungi

with A. oligospora being widespread and a possible candidate for biological control of plant parasitic nematodes.

Macrofauna diversity and abundance across different land use systems in Embu, Kenya

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Abstract: This paper presents data on diversity and abundance of soil macrofauna present in soil collected from natural forest, plantation forest, fallow, coffee, tea, napier, and maize land use systems. From each of these land uses soil samples were taken for macrofauna assessment using three sampling methods (monolith, transect and pitfall traps).Thirty four (34) genera/species of soil macrofauna were recorded, the highest number (27) being observed in napier. Rényi diversity profile indicates that in terms of species richness (α at ∞), plantation forest was the richest of all land use systems, followed by coffee>napier>natural forest with fallow/pasture being least rich in species, maize and tea were not different from each other in richness. It was however not possible to clearly order the land use system in terms of species diversity as indicated by the diversity indices. Shannon index of diversity (α=1) indicated that coffee was most diverse of the land use systems followed by plantation forest>natural forest>napier>maize>tea, while fallow/pasture was least diverse in macrofauna species. On the other hand, Simpson's diversity (α=0) indicated that maize was the most diverse followed by fallowed by fallow=napier=coffee>tea>natural forest>plantation forest. Rényi evenness profile indicated that species distribution was most even in the plantation forest followed by natural forest and coffee>napier>tea>maize but least even in fallow/pasture. Hymenoptera were most abundant of the macrofauna groups constituting about 45% of the total followed by Isoptera (39%), Coleoptera (6%), Oligochaeta (5%), Orthoptera (3%) and Arenae (2%). The other groups that comprised of Hemiptera, Diptera, Phasmidae and Blattelidae each constituted <1% of the total marofauna recorded. Highest macrofauna density (1566) were recorded in the napier followed by fallow (1356)>coffee (1170)>natural forest (1110)>tea (755) but lowest in plantation forest (309). This study demonstrated that changes in diversity and density of soil fauna communities occurred when land use systems were subjected to varying levels of intensification. The significant correlations between macrofauna groups with selected soil chemical properties showed that soil fertility had played some role in influencing the density, distribution and structure of macrofauna communities.

Soil macrofauna community structure across land use systems of Taita, Kenya

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Abstract: Diversity and abundance of soil macrofauna in natural forest, plantation forest, fallow, coffee, Napier, and maize, horticulture land use systems was studied. Sampling of the

macro fauna organisms from the soil was carried out using three sampling methods which were monolith, transect and pitfall trapping. Seventy eight (78) genera/species were recorded across the different land use systems of Taita. In terms of species richness (α at ∞), plantation forest was the richest of all the land use systems, followed by horticulture> napier, coffee>natural forest>coffee>fallow and maize was least rich. The Shannon index of diversity (α=1) indicated that plantation forest was the most diverse of the land use systems followed by natural forest>horticulture>napier>coffee, while fallow and maize were least diverse. The Rényi evenness profile indicated that plantation forest were most even in terms of species distribution which was least in maize.The major macrofauna groups recorded in the Taita benchmark site included: Hymenoptera, Isoptera, Coleoptera, Oligochaeta and Orthoptera and Arenae. Generally Hymenoptera were the most abundant of the macrofauna groups constituting about 36% of the total followed by Isoptera (22%), Oligochaeta (16%), Coleoptera (10%). The other macrofauna (*Arenae, Diplopoda, Diptera, Orthoptera, Blattidae, Isopoda, Chilopoda- Geopholomorpha, Hemiptera, Opiliones,Chiopoda-Scolopendromorpha, Lepidoptera, Dermaptera, Phasmidae, Blattelidae* and *Mantodea* each constituted <10% of the total macrofauna recorded. Hymenoptera was ranked highest as it had the highest total abundance (number of individuals m-2) of 59,440 while Mantodea was ranked 18th and had the lowest total abundance of 16. Macrofauna density (number of individuals m-2) was highly variable across land use systems. Generally macrofauna density was higher in arable systems than forests. Although analysis of variance (ANOVA) indicated insignificant differences among the land use systems, highest macrofauna density (4929) were recorded in the fallow followed by coffee (3315)>maize (3257)>horticulture (2950)>natural forest (2119) but lowest in the plantation forest (1131). Except for Chilopoda-Geopholomorpha, Chilopoda- colopendromorpha and Isopoda, all the other macrofauna groups were not significantly different across landuse systems. The variation in macrofauna diversity appear to be influenced by management practices that most of which involve destruction of nesting niches, modification of soil microclimate within these habitats and removal of substrate.

Nematode Community Structure as Influenced by Land Use and Intensity of Cultivation

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Abstract: This study was conducted to determine the effect of land use and intensity of land cultivation on the nematode community structure. The land use types represented in the study sites were natural forest, plantation forest, tea, coffee, napier grass, agroforestry, fallow and annual crop cultivation dominated by maize intercropped with beans. Nematode diversity and abundance decreased with intensity of land cultivation, with the natural forest being regarded as the benchmark. The decrease in nematode diversity was assessed using Shannon, Simpson and species richness indices and was used to reflect the underlying changes in physical, chemical and biological properties of soil environment. The highest maturity indices for free-living and plant parasitic index were recorded in the natural forest and intensively cultivated land under annual crops (maize/beans), respectively. Plant parasitic nematodes were predominant in soils that were under agricultural production while saprofagic nematodes dominated the forested land as exemplified by the ratios of free-living to plant parasitic which were, 5.18 and 0.54 in the natural forest and annual crop production systems respectively. Changes in the nematode community structure, as exhibited by diversity indices, may be a reflection of real differences in the soil characteristics and changes in ecosystem functions.

Occurrence of arbuscular mycorrhizal fungi (amf) in the high altitude regions of Mt. Kenya

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Abstract: A survey was carried out to establish the effects of Land Use Types (LUT) on Arbuscular Mycorrhiza Fungi (AMF). AMF spore abundance, species richness, distribution and diversity were evaluated in field soils and trap cultures. The percentage root colonization was assessed in trap plants only. AMF were identified and enumerated from spores extracted directly from field and trap culture soils. Soils were sampled from 60 sampling points occurring in three windows in central Kenya. A total of 20 AMF species were isolated and 13 assigned species status. The field soils had more (18) AMF species than trap cultures soils (12). The spore community was dominated by *Acaulosporaceae,* and *Glomaceae*. Land use type and window had no significant ($p<0.05$) effect on AMF spore abundance or root colonization. However trends were observed with land use under cultivation recording the highest AMF spore abundance and land use with minimum or not under cultivation the least spore abundance and highest root colonization. AMF species diversity was highest in LUT without crops. Species distribution was variable in land use type, with nutrients explaining similarities amongst land use types. Land use type with highest similarities shared some environmental parameters and AMF species. Carbon, nitrogen and potassium had positive effects on AMF abundance while Phosphorus and acidity had negative effects on AMF spore abundance. Few AMF species also showed preference for land use type and nutrients.

Spatial distribution of *trichoderma* sp. in Embu and Taita regions, Kenya

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Abstract: The distribution of *Trichoderma* species in soils of Embu and Taita regions in Kenya with relation to land use practices was investigated. The study areas were chosen because of their significant land use intensification and for being biodiversity hot spots. Soil washing and dilution plate techniques were used to recover *Trichoderma* spp from the soil samples collected from different land use types. The fungal isolates were identified and assigned to nine species from Embu soils and eleven species from the Taita soils. Greater populations were however observed in Embu than in Taita. Geographic differences between the regions mostly explain the differences in ecological niches of the two regions that result to different soil assemblages and plant types in the regions and therefore variation in available substrate for the fungus. Land use at each site affected the distribution, richness and abundance of *Trichoderma* with Napier grass having the highest abundance in both Embu and Taita while coffee had the lowest richness and abundance. *Trichoderma* favoured plants with shallow and widely spreading rooting systems, compared to the deeply rooted perennial coffee and tea trees. This was further evident in the results of the study on the effect of soil depth that showed that it was not the vertical soil depth of the soil from the top that determined *Trichoderma* abundance but rather substrate availability in Taita and rooting

systems in Embu. This underpins the importance of plant type and in effect land use system in the abundance of *Trichoderma*. The unevenness in the distribution of *Trichoderma* within the LUTs suggests yet another factor influencing the distribution of *Trichoderma* apart from the LUTs. Unevenness was greater in Embu than in Taita. The differences could mostly be attributed to soil management practices employed by different farmers while managing their land and crops differently. *Trichoderma harziunum* was the most frequently isolated species and the most abundant in both Embu and Taita. The presence of *Trichoderma* species in some land use types and the absence in others, provides a clue on the most preferred habitats, plants and/or crops. Considering the beneficial aspects of *Trichoderma* such as being antagonistic to the pathogenic fungi, crops or plants such as napier grass that induce high abundance and richness of *Trichoderma* can be used in crop rotations or in combinations with other crops to maintain high levels of the fungus in the soil. The effect of increasing the rooting surface area of the disadvantaged crop through the colonization of the younger roots by the fungus would enhance nutrient uptake by the crops. This would have a direct effect of increasing the yields while also reducing the incidence of other fungal diseases.

Impact of land use on distribution and diversity of *fusarium* spp. in Taita Taveta, Kenya

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Abstract: The effect of current Land Use Types (LUTs) and soil depth on distribution and diversity of soil *Fusarium* species was carried out in Taita Taveta district, Kenya. Soil samples were collected from sixty sampling points across a land use gradient covering six different LUTs, at the depths of 0 to 10 and 10 to 20 cm. Using *Fusarium*-selective media, a total of 1865 *Fusarium* isolates were recovered from the soil samples which resulted into 26 *Fusarium* species. *Fusarium oxysporum* and *Fusarium solani* were the dominant species in this area. Difference in *Fusarium* abundance, diversity and richness across the LUTs was significant ($P<0.001$) with horticulture being the richest and the most diverse LUT. The top soil layer had significantly higher *Fusarium* abundance and richness ($P<0.05$). Principal Component Analysis (PCA) based on the relative *Fusarium* species abundance differentiated the LUTs with 79.69% variance explained by the first and second components.

WORK IN PROGRESS

Site characterization and inventory of Below-Ground Biodiversity in a semi-deciduous forest margin

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This book presents the results from the inventory of below ground biodiversity in the Oumé benchmark site of Ivory Coast, one of the benchmark sites of the "Conservation and Sustainable Management of Below Ground Biodiversity" project. The book contains chapters on selection and characterization of the benchmark area in terms of land use, agricultural systems and socio-economic and cultural characteristics. One chapter deals with the morphological, physical and chemical characteristics of the soils found in the area and there is a separate chapter on the soil organic carbon and nitrogen dynamics in the soils. The functions and taxonomic groups inventoried and reported on are: Earthworms, and their response to human disturbance regimes, the impact of land use types on ant communities as well as the effects of land use change on the diversity of termite species. There is a separate chapter on the diversity and abundance of beetles as affected by the various land use types. Further there are separate chapters on the abundance and diversity of collembolan, the effects of land use type on plant parasitic nematode population, the result from the inventory of soil fungi (plant parasitic and antagonistic fungi), result from the investigation of rhizobia resources and arbuscular mycorrhizal fungi. A synthesis chapter reports on the factorial analyses of the distribution of the various functional groups of soil organisms and the relation with land use and soil properties and derived integrated soil quality indicators from this analyses.

Output 1. Biophysical processes and soil health
Output Targets 2009: Indicators of soil (biological) quality identified and documented.

COMPLETED WORK

Using nematode functional group abundance as soil quality indicators in tropical ecosystems

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Abstract: Soil quality indicators and nematode abundance were characterized in a tropical agroecosystem to evaluate the relationship between soil quality indicators and nematode functional groups. Soil quality indicators were generated from principal soil properties; soil organic (SOC), total nitrogen (TN), extractable phosphorus (Ext. P), exchangeable calcium (Ca), Magnesium(Mg), sodium (Na) and soil texture (sand clay and silt). Principal component analysis (PCA) was used to summarize the variability in soil properties and provide the soil quality indicators (GSQIs). Identification of nematode into different genera was done using a centrifuge method followed by a classification into functional groups as outlined by Yeates Method 1993. The functional groups were identified include; omnivorous, bacterial feeding, substrate ingestion, animal predation, unicellular eukaryote feeding, dispersal or infective stages of animal parasites, Plant feeding. Canonical correspondence analysis indicated that different genera can be associated with soil properties. There was a strong relationship with p value of <0.001 between the nematode functional groups and the soil properties. For example; SOC and TN were closely associated with the bacterial and hyphal feeding functional group. Sedimentary parasites had a positive relation with Ext. P where their total abundance increased with high levels of exchangeable P while low levels of sand were associated with low population of semi endo-parasites. The bacterial and hyphal feeding nematodes indicated good soil quality because of their positive associated with SOC, an important soil variable that plays a key role in the structure of soil and nutrient retention and has been accepted universally an indicator of soil quality. This study demonstrated the potential of nematode functional groups as indicators of soil quality because different categories were associated with the principal soil nutrients.

Can arbuscular mycorrhizal fungi (AMF) be indicators of soil quality?

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Abstract: Arbuscular mycorrhizal fungi (AMF) were studied in different land use types from seven tropical countries and their potential as soil quality indicators. The potential of AMF genera as a diagnostic tool for soil quality was assessed. Soil properties examined were pHw, total carbon (TC), total nitrogen (TN), extractable phosphorus (Ext. P), exchangeable potassium (K), exchangeable calcium (Ca), exchangeable magnesium (Mg), sand, silt, and clay, which were analyzed using standard laboratory methods widely used for tropical soils. Land use types were classified into 16 classes. Multivariate analysis of principle component (PCA) was used to generate general soil quality indicators through a linear combination of chemical and physical properties that gave a holistic representation of the soil quality. AMF species were identified in samples from field and/or trap cultures, belonging to AMF genera; Glomus, Gigaspora, Scutellospora, Acaulospora, and Entrophospora. The identification of AMF was made by observation of spore morphology and confirmed by sequencing. Canonical correspondence analysis indicated that different genera can be associated with soil properties. The general indicators of soil quality developed and used to identify which AMF genera could be a genus indicator of soil quality. Scutellospora was established to be the appropriate genus that mostly acts as an indicator genus of soil quality since its total abundance increased as the general soil fertility score increased from negative to positive. However, the general Mycospora showed an inverse relationship with an increase in the soil fertility score leading to a decreased abundance of Mycospora, which may be attributed to its pathogenic characteristics. This study indicated the potential of soil AMF genera as useful biological indicators of soil quality.

Use of nematode destroying fungi as indicators of land disturbance in Taita Taveta, Kenya. *(2009) Tropical and Subtropical Agroecosystems, v. 11, No 2*

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Abstracts: This study was undertaken to determine whether nematode destroying fungi can be used as indicators of soil disturbances. Soil samples were collected from an indigenous forest, maize/bean, napier grass, shrub and vegetable fields, which represented the main land use types in Taita Taveta district of Kenya. The fungal isolates obtained were grouped into seven genera. The species identified were, *Acrostalagums obovatus, Arthrobotrys dactyloides*, *Arthrobotrys oligospora, Arthrobotrys superba, Dactyllela lobata, Haptoglosa heterospora, Harposporium anguillulae, Harposporium.sp, Monacrosporium cionopagum* and *Nematoctonous georgenious.* Occurrence of nematode destroying fungi was significantly ($P = 3.81 \times 10^{-7}$) different among the land use systems in the study area. Out of the isolates that were positively identified, 33.7 %, 27.9 %, 20.9 %, 11.6 % and 5.8 % were from fields under vegetable, maize/bean, napier grass, shrub and forest, respectively. Soil disturbance accounted for the highest occurrence of nematode destroying fungi (60.77 %) of the two main factors in the principal component analysis. While moisture, the second factor accounted for 23.35%. Fungal isolates from vegetable gardens were most diverse but the least even while

the forest land use was most even but least diverse. The total richness of nematode destroying fungi was 9, in vegetable and maize/bean fields while was 7, 6, and 3 in napier, shrub and forest habitats respectively in their decreasing order of disturbance. This study has established that nematode destroying fungi increases with increased land disturbance.

WORK IN PROGRESS

Tropical Soil Biodiversity and Land Use Change

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Scope: Loss of soil biodiversity as result of land use change and its effect on soil quality has emerged as one of the most exciting and dynamic areas in agro-ecology. Anthropogenic pressure leading to increased land use intensity may easily results in degradation of soils in terms of reduced soil ecosystem functioning. However, loss of soil biodiversity and its effect on soil quality has not been widely reported, especially not for tropical regions. The proposed book provides a comprehensive and balanced coverage of trends in soil biodiversity loss and its effect on soil quality observed across a land use intensity gradient in the forest margins of biodiversity hotspot areas and agro-ecological regions of global significance. This book provides the synthesis of the results obtained from the inventory of below-ground biodiversity conducted in 11 benchmark sites located in seven countries across the tropics (Brazil, Mexico, Cote d'Ivoire, Uganda, Kenya, India and Indonesia), by the GEF-funded project on the 'Conservation and Sustainable Management of Below-ground Biodiversity' (CSM-BGBD), implemented by the Tropical Soil Biology and Fertility institute of CIAT with implementation support from UNEP. Soil biodiversity is addressed in terms of taxonomic richness for major taxonomic groups and in terms of biodiversity associated with the most important functional groups of soil organisms. Results of the inventory are interpreted in terms of soil quality, addressing its chemical, physical and especially its soil biological aspects, for which purpose quality indicators are derived. Common trends but also differences between sites and regions are evaluated.

The following chapters are proposed for the book:

Chapter 1: Soil biodiversity, quality and health: concepts and application.
Chapter 2: Contrasting benchmark sites across the seven tropical countries: biophysical and socio-economic characteristics
Chapter 3: Soil quality variation across tropical landscapes; organic, chemical and physical properties
Chapter 4: Soil biological diversity as determined by land use type
Chapter 5: Soil biota as indicators of soil quality across tropical landscapes
Chapter 6: Abuscular Mycorrihzal Fungi (AMF) diversity and abundance as related to land use change
Chapter 7: Leguminosae nodulating bacteria diversity and abundance as land use changes in tropical countries
Chapter 8: Nematode diversity and abundance in relation to land use change and soil quality in the tropics
Chapter 9: Mesofauna composition and density in tropical ecosystems
Chapter 10: Response of earthworm populations to disturbance in tropical forests margins
Chapter 11: Impact of land use change on termite communities in the tropics

Chapter 12: Impact of land use change on ants in tropical environment
Chapter 13: Macrofauna communities influence by land use change in the tropics
Chapter 14: Influence of land use change on distribution of fungi in tropical soils
Chapter 15: Is there a relationship between above ground and below ground biodiversity

Output 1. Biophysical Processes and soil health
Output Target 2009: Concepts of valuating the contribution of soil biota and biotic processes to the provision ecosystem goods and services applied in case studies

COMPLETED WORK

Earthworms influence the production of above- and belowground biomass and the expression of genes involved in cell proliferation and stress responses in Arabidopsis thaliana *(2009) Soil biology and biochemistry, 42 (2): 244-252*

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Abstract: To better understand the complex mechanisms of action of earthworms on plants, we set up an experimental system using the model plant Arabidopsis thaliana (L) Heynh, Aporrectodea caliginosa a common temperate earthworm and two types of soil with contrasted contents in organic matter and nutrients. Changes in plant biomass, biomass allocation to roots, leaves and stems and C/N ratios were related to variations in the expression of several plant genes involved in cellular division and stress responses and with earthworm-induced alterations in soil mineral status.
In the poorest soil, i.e. with low contents in mineral nutrient and organic matter, earthworms increased soil nitrate content very significantly and boosted plant aboveground biomass production. This correlated with changes in leaf transcript accumulation suggesting enhanced cell division and lesser incidence of reactive oxygen species. In the richer soil, earthworms had no significant effect on the production of aerial biomass. However, several plant responses were observed regardless of soil quality: enhanced accumulation of an auxin-responsive transcript in the leaves, a strong decrease in root length and biomass and a reduction in C/N values, particularly in the bolt stems. Although these results pointed out earthworm-induced enhancement of mineralization as a determining factor in the formidable plant growth responses, the release in the drilosphere of phytohormone-like compounds by earthworm-activated bacteria was most likely implicated as well in this process and resulted in "forced" nitrogen uptake by the plants. The herein demonstrated sensitivity of the model plant A. thaliana to earthworms shows that such new experimental set up could become a central key to the development of multidisciplinary investigations on plant-soil interactions.

Ecology and the challenge of a multifunctional use of soil *(2009) Pesquisa agropecuaria brasileira, 44 (8): 803-810*

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Abstract: Soil zoology and soil ecology have become very active fields of research since the early 1990s. A search in the ISI Web of Science databases showed a steady increase in publications about that theme over the last two decades, and 3,612 bibliographic references were found for that theme for the period of 2004 to 2008. The researches covered mostly soil environmental issues, toxicology and ecology. The issue of theoretical development in soil ecology is discussed, and arguments are presented against the idea that the soil ecology theory is deficient. Finally, the need for a general model of soil function and soil management is discussed and some options are presented to reach this goal.

Microbial biomass, enzyme and mineralization activity in relation to soil organic C, N and P turnover influenced by acid metal stress *(2009) Soil biology and biochemistry, 41 (5): 969-977*

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Abstract: This study focused on the potential of using soil microbial biomass, enzyme and mineralization activities involved in organic C, N and P turnover, to evaluate the quality of a subtropical agricultural soil affected by long-term acid metal stress. Fractions of C, N and P involved in soil organic matter, microbial biomass and mineralization processes were estimated. Total enzyme activity (FDA) and eight hydrolase activities (xylanase, amylase, beta-glucosidase, invertase, N-acteyl-glucosaminidase, urease, alkaline and acid phosphatases) in different decomposition stages of organic C, N and P were selected to characterize the soil functional diversity. These biological datasets were compared with soil metal variables (total contents and free and -complex ions of Cu, Pb, Zn, Cd, Al and Mn), using principal component analyses, co-inertia and discriminant analyses. The multiple statistics indicate that the metal variables were significantly related with not only general biological factors, but also respective datasets of biomass, enzyme activities and mineralization rates (all $P < 0.001$). In general, metal variables were inversely related to parameters and indices of microbial biomass C, N and P, FDA and C-related polysaccharidase and heterosidase activities, and P mineralization. As comparison, metal variables exhibited positive relationships with parameters and indices of N-related N-acteyl-glucosaminidase, urease, ammonification, total N mineralization and metabolic quotient, compared with inhibited nitrification. Specifically, free and complexed metal cations showed higher bioavailability than total contents in most cases. Cu, Pb, Al and Mn had different ecotoxicological impacts than Cd and Zn did. Stepwise regression models demonstrated that metal variables are key stress factors, but most of them excluded soil pH. Furthermore, spatial distribution in land uses and of sampling sites clearly separated the soil samples in these models ($P<0.001$). We conclude that such a statistical analysis of microbiological and biochemical indices can provide a reliable and comprehensive indication of changes in soil quality and organic nutrient cycling, after exposure to long-term acid metal stress.

WORK IN PROGRESS

Economic Evaluation of Below-Ground Biodiversity; Report of workshop held from 7 - 12 December 2009

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The CSM-BGBD project conducted a workshop on the economic evaluation of BGBD. The workshop was conducted from 7 – 12 December 2009, in Kampala, Uganda. The report will be issued in 2009. Apart from a report on the proceedings of the workshop a technical report will be written on the evaluation of below-ground biodiversity. The technical report will contain the following chapters:

- Framework for the evaluation of below-ground biodiversity.
- Methods and techniques for the economic evaluation of BGBD related products and services.
- Case studies related to nutrient cycling.
- Case studies related to soil structure improvement and related hydraulogical properties.
- Case studies related to pest and disease management through biological interventions.
- Knowledge, Attitude and Practice of various stakeholder groups with respect to soil biodiversity.
- Policy analyses and recommendation n view of management of BGBD.

Output 1. Biophysical Processes and soil health
Output Target 2010: Modelling tools to predict effect of soil management interventions and technologies on soil health status developed and validated.

COMPLETED WORK

Nitrogen and phosphorus capture and recovery efficiencies and crop responses to a range of soil fertility management strategies in sub-Saharan Africa *(2009) Nutrient Cycling in Agroecosystems - ISSN 1385-1314*

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Abstract: This paper examines a number of agronomic field experiments in different regions of sub-Saharan Africa to assess the associated variability in the efficiencies with which applied and available nutrients are taken up by crops under a wide range of management and environmental conditions. We consider N and P capture efficiencies (NCE and PCE, kg uptake kg-1 nutrient availability), and N and P recovery efficiencies (NRE and PRE, kg uptake kg-1 nutrient added). The analyzed cropping systems employed different soil fertility

management practices that included (1) N and P mineral fertilizers (as sole or their combinations) (2) cattle manure composted then applied or applied directly to fields through animal corralling, and legume based systems separated into (3) improved fallows/cover crops cereal sequences, and (4) grain legume-cereal rotations. Crop responses to added nutrients varied widely, which is a logical consequence of the wide diversity in the balance of production resources across regions from arid through wet tropics, coupled with an equally large array of management practices and inter-season variability. The NCE ranged from 0.05 to 0.98 kg kg-1 for the different systems (NP fertilizers, 0.16–0.98; fallow/cover crops, 0.05–0.75; animal manure, 0.10–0.74 kg kg-1), while PCE ranged from 0.09 to 0.71 kg kg-1, depending on soil conditions. The respective NREs averaged 0.38, 0.23 and 0.25 kg kg-1. Cases were found where NREs were >1 for mineral fertilizers or negative when poor quality manure immobilized soil N, while response to P was in many cases poor due to P fixation by soils. Other than good agronomy, it was apparent that flexible systems of fertilization that vary N input according to the current seasonal rainfall pattern offer opportunities for high resource capture and recovery efficiencies in semi-arid areas. We suggest the use of cropping systems modeling approaches to hasten the understanding of Africa's complex cropping systems.

Output 1. Biophysical Processes and soil health
Output Target 2010: Methods for evaluating soil health status (provision ecosystem goods and services) developed and accepted.

As part of the work on the evidence-based and spatially-explicit soil management recommendations we aim to include economic evaluation of the soil and land health status and land degradation, hoping to provide an economic basis to the recommendations on soil and land management. At this point, all the work is in progress.

Output 1. Biophysical Processes and soil health
Output Target 2010: The social, gender, and livelihood constraints and priorities affecting the sustainable management of soils identified especially in relation to improved SOM management and management of BGBD.

The work on socio-economic constraints to sustainable land management is singled out as a separate activity. The socio-economic baseline survey that is being carried out in a number of projects will fall under this activity, as well as ex-ante adoption studies. Gender is an important issue and will be given specific attention in the AfSIS project.

Output 1: Biophysical Processes and soil health
Output Target 2011: Decision support framework for targeting soil management recommendation (ISFM and INRM technologies) at landscape level established.

COMPLETED WORK

The decision support framework is a longer term goal of the SLM programme. The idea is to build on decision support tools for crop selection, organic matter management, selection of appropriate ISFM options and farm management within a landscape context. That is taking into account the general production objectives for the particular landscape and the position within the landscape. Under this output we report on the various modeling efforts as well as on the integration of these models into a decision support framework for sustainable land management.

Effect of farmer management strategies on spatial variability of soil fertility and crop nutrient uptake in contrasting agro-ecological zones in Zimbabwe. *Nutrient Cycling in Agroecosystems1385-1314 (Print) 1573-0867 (Online)*

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Abstract: Variability of soil fertility within, and across farms, poses a major challenge for increasing crop productivity in smallholder systems of sub-Saharan Africa (SSA). This study assessed the effect of farmers' resource endowment and nutrient management strategies on variability in soil fertility and plant nutrient uptake between different fields in Gokwe South (~650 mm yr^{-1}) and Murewa (~850 mm yr^{-1}) districts, Zimbabwe. In Murewa, resource-endowed farmers applied manure (>3.5 t ha^{-1} yr^{-1}) on fields closest to homesteads (homefields) and none to fields further away (outfields), and in Gokwe the manure was not targeted to any particular field. Soil available P was more concentrated on homefields (8-13 mg kg^{-1}) of resource-endowed farmers than on outfields and all fields on poor farms (2-6 mg kg^{-1}). Soil fertility in Murewa decreased with increasing distance from the homestead while the reverse trend occurred in Gokwe South, indicating the impact of different soil fertility management strategies on spatial soil fertility gradients. In both districts, maize nutrient uptake showed deficiency in N and P, implying that these were the most limiting nutrients. It was concluded that besides farmers access to resources and management strategies, the direction of soil fertility gradients also depends on agro-ecological conditions.

CROSPAL, software that uses agronomic expert knowledge to assist modules selection for crop growth simulation *(2009) Environmental Modelling and Software v. 25, (8) 946-955*

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Abstract: Crop growth models are used for a wide range of objectives. For each objective a specific model has to be developed, because the reusability of a model is often limited by the necessity of a fundamental restructuring to adapt it to a different objective. To overcome this limitation, we developed a method to facilitate model restructuring by a novel combination of software technology with expert knowledge. This resulted in the decision-making software application CROSPAL (CROp Simulator: Picking and Assembling Libraries). CROSPAL includes (1) a library of processes each containing different modeling approaches for each crop physiological process and (2) a procedure based on expert knowledge of how to

combine the different processes for the objective of the simulation. A brief overview of the state of the art in crop modelling is presented, followed by an account of the developed concept to improve flexibility in crop modelling considering expert knowledge. We describe the design of the software and how expert knowledge is integrated. The use of CROSPAL is illustrated for the modelling of crop phenology. We conclude that CROSPAL is a helpful tool to improve flexibility in crop modelling considering expert knowledge but further development and evaluation is required to extend its range of application to more processes and issues crop modelling is presently addressing.

Output 1. Biophysical Processes and soil health
Output Target 2011: *Tools and techniques* for rapid appraisal of soil health status and gradients at landscape level developed

This output will very much be a part of the decision support framework. As mentioned before the development of tools and ethods for the assessment of soil and land health status is an ongoing process for which different output target are defined for the subsequent years. Whereas in the beginning these tools focus on the surveillance techniques, standard protocols and operation procedures, later on these tools will be more directed towards appraisal and evaluation (i.e. the diagnostic tools) and tools that apply explicitly to the landscape level.

Output 1; Biophysical Processes and soil health
Output Target 2011: Tools and methods developed for rapid appraisal of agricultural production landscapes especially with respect to socio-economic drivers for land and soil degradation and socio-economic constraints for improving soil productivity and soil health; mapping of the socio-cultural and policy environment (production potential, social & human, economic, natural capital)

Tools are required to characterize agricultural production landscapes in terms of social and economic characteristics, and how these might relate to particular land degradation problems. To some extent this work will include validation of approaches adopted by others in identification of development domains and work done by HArvestChoice for example. No completed work or work in progress to report on.

III.2. OUTPUT 2 - ECONOMICALLY VIABLE AND ENVIRONMENTALLY SOUND SOIL MANAGEMENT PRACTICES DEVELOPED AND TESTED, WITH EMPHASIS ON MANAGEMENT OF SOIL BIOLOGICAL RESOURCES.

Outputs (Intended users)	**Outcome (Impact)**
Description: Economically viable and environmentally sound soil management practices developed and tested, with emphasis on direct and indirect management of soil biological resources for low- and medium external input agricultural systems. Intended users: CGIAR, ARI, researchers from NARS and local universities, NGOs, farmer groups, private sector agents, extension services, and regional consortia, conservation agencies.	Outcome: Technologies and soil management strategies available for range of agro-ecological and socio-economic conditions provides viable options for various stakeholder groups and increases adoption of improved technologies. Impact: Increased sustainability of productions systems and improved security of farmers in target impact areas.

Soil health management practices; landscape management

Intensification pathways for low input agriculture will have to target investment in maintaining and improving the natural resource base, i.e. aim to restore ecological functioning to minimize the need for external inputs. To this end, options for direct and indirect management of below-ground biodiversity will be investigated and evaluated. This will refer to the crop diversification strategies, improved organic matter management, reduced tillage operations and inoculation with beneficial soil organisms in various forms. Some of these technologies should be placed in the realm of ISFM; e.g. the use of bio-fertilizers. The concern of the SLM programme is to what extent these options provide solutions for soil and land health issues at landscape level. For this purpose the SLM looks at the implementation of these management options within the farm context and within the larger landscape context (i.e. evaluate possible measures within an area wide approach). The relevant questions relate to resource allocation on farm and within the landscape and how this can be approved. Apart from this there are measures to be considered that specifically applies to the landscape level. This may refer to measures like putting windbreaks in, terracing et al., or even stimulating differentiation in land use. Tools and techniques for evaluation of ecosystem services from output 1 will result in improved appreciation of critical elements or components within the land use system and the landscape and soil conservation including below-ground biodiversity.

Major research questions are:

→ *What is the soil biological quality of soils under alternative land use systems like conservation agriculture and organic farming and does it differ from traditional agricultural practices?*

→ *What is the effect of indirect management practices, and especially improved soil organic matter management practices on BGBD and how does this effect soil health?*

→ *What is the short term and longer term effect of direct inoculation with various beneficial organisms on BGBD and food web structure ad herewith with the provision of ecosystem services (stability of the food webs)?*

→ *What are the options for improving resource allocation in the various agricultural production landscapes?*

→ *What are the competing claims on resources within the landscape in relation to the different uses and users of these resources and how can these competing claims be accommodated.*

→ *How can land and soil resources be better protected or conserved by improving resource allocation within production landscapes and what are the tools and techniques to model and predict the effects on resource allocation at landscape level?*

Output 2. Soil management practices
Output Target 2009: Local baselines and interviews show that farmers' understanding of soil biological processes and soil health status is demonstrably enhanced in at least 5 benchmark sites.

COMPLETED WORK

Soil macrofauna under integrated crop-livestock systems in a Brazilian Cerrado Ferralsol *(2009) Pesquisa Agropecuária Brasileira v.44 (8) 1011-1020*

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Abstract: The objective of this work was to assess the effects of integrated crop-livestock systems, associated with two tillage and two fertilization regimes, on the abundance and diversity of the soil macrofauna. Four different management systems were studied: continuous pasture (mixed grass); continuous crop; two crop-livestock rotations (crop/pasture and pasture/crop); and native Cerrado as a control. Macrofauna was sampled using a modified Tropical Soil Biology and Fertility method, and all individuals were counted and identified at the morphospecies level for each plot. A total of 194 morphospecies were found, distributed among 30 groups, and the most representative in decreasing order of density were: Isoptera, Coleoptera larvae, Formicidae, Oligochaeta, Coleoptera adult, Diplopoda, Hemiptera, Diptera larvae, Arachnida, Chilopoda, Lepidoptera, Gasteropoda, Blattodea and Orthoptera. Soil management systems and tillage regimes affected the structure of soil macrofauna, and integrated crop-livestock systems, associated with no-tillage, especially with grass/legume species associations, had more favorable conditions for the development of "soil engineers" compared with continuous pasture or arable crops. Soil macrofauna density and diversity, assessed at morphospecies level, are effective data to measure the impact of land use in Cerrado soils.

Spatial patterns of grasses influence soil macrofauna biodiversity in Amazonian pastures *(2009) Soil Biology and Biochemistry 41 586 – 593*

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Abstract: Grasslands are often characterized by small-scale spatial heterogeneity due to the juxtaposition of grass tufts and bare ground. Although the mechanisms generating plant spatial patterns have been widely studied, few studies concentrated on the consequences of these patterns on belowground macrofauna. Our objective was to analyze the impact of grass tuft (Brachiaria bryzantha cv. marandu) spatial distribution on soil macrofauna diversity in Amazonian pastures, at a small scale (less than 9 m (2). Soil macrofauna was sampled among B. bryzantha tufts, which showed a variable spatial distribution ranging from dense to loose vegetation cover. The vegetation configuration explained 69% of the variation in total soil macrofauna density and 68% of the variation in total species richness. Soil macrofauna was mainly found in the upper 10 cm of soil and biodiversity decreased with increasing distances to the nearest grass tuft and increased with increasing vegetation cover. The size of the largest grass tuft and the microlandscape connectivity also had a significant effect on biodiversity. The density and species richness of the three principal soil ecological engineers (earthworms, ants and termites) showed the best correlations with vegetation configuration. In addition, soil temperature significantly decreased near the plants, while soil water content was not influenced by the grass tufts. We conclude that soil macrofauna diversity is low in pastures except close to the grass tufts, which can thus be considered as biodiversity hotspots. The spatial arrangement of B. bryzantha tussocks influences soil macrofauna biodiversity by modifying soil properties in their vicinity. The possible mechanisms by which these plants could affect soil macrofauna are discussed.

WORK IN PROGRESS

Knowledge, Perceptions and Practices of various stakeholder groups in relation to management of soil health (below-ground biodiversity) in the Benchmark sites of the CSM-BGBD project

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In the CSM-BGBD project various studies have been done that look at the knowledge attitudes and practices of farmers and other stakeholder groups with respect to the role of soil biota in maintaining soil health and the management of soil biological resources. Results have been presented at the various workshops organised by the CSM-BGBD project, notably the workshop on Economic Evaluation of BGBD that was held form 7 - 12 December 2009, in Uganda. A comprehensive report with results from the various studies will be issued in 2010.

Output 2. Soil management practices
Output Target 2009: Direct and indirect options to manage BGBD that enhance locally important ecosystem services demonstrated.

COMPLETED WORK

Effect of Trichoderma Harzianum and Arbuscular Mycorrhizal Fungi on the Growth in Tomato

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Abstract: A green house study was conducted to investigate the ability of an isolate of *Trichoderma harzianum* (P52) and arbuscular mycorrhizal fungi (AMF) in enhancing growth and control of a wilt pathogen caused by *Fusarium oxysporum* f. sp. *lycopersici* in tomato seedlings. The plants were grown in plastic pots filled with sterilized soils. There were four treatments applied as follows; P52, AMF, AMF + P52 and a control. A completely randomized design was used and growth measurements and disease assessment taken after 3, 6 and 9 weeks. Treatments that significantly ($P < 0.05$) enhanced heights and root dry weights were P52, AMF and a treatment with a combination of both P52 and AMF. The treatment with both P52 and AMF significantly ($P < 0.05$) enhanced all growth parameters (heights; shoot and root dry weight) investigated compared to the control. Disease severity was generally lower in tomato plants grown with isolate P52 and AMF fungi either individually or when combined together, though the effect was not statistically significant ($P \geq 0.05$). A treatment combination of P52 + AMF had less trend of severity as compared to each individual fungus. *Trichorderma harzianum* and AMF can be used to enhance growth in tomato seedlings.

Earthworms, soil fertility and aggregate-associated soil organic matter dynamics in the Quesungual agroforestry system *(2009) Geoderma v. 155, 3-4, 320-328*

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Abstract: Issues of food security, environmental degradation and global climate change underscore the need for the improved understanding of sustainable agricultural systems around the globe. The Quesungual slash-and mulch agroforestry system (QSMAS) of western Honduras offers a promising alternative to traditional slash-and-burn (SB) agriculture for the mountainous tropical dry forest zones of Central America, but the overall influence of this system on soils is not fully understood. We examined earthworm populations, soil fertility and soil organic matter (SOM) dynamics under QSMAS and SB agriculture, with secondary forest (SF) as a reference. Both QSMAS and SB consisted of treatments with and without inorganic fertilizer (N–P–K) additions, resulting in five management treatments, each present on three replicate farms. Baseline soil samples (0–15 cm) were collected prior to forest

clearing and establishment of QSMAS plots in 2003 and in SB and SF plots in 2005 to determine initial soil concentrations of C and N. Soils were sampled in 2006 and 2007 for bulk soil C and N and P availability, as well as for aggregate fractionation and determination of C and N within the different aggregate size fractions. Earthworm populations were assessed in July 2007. Earthworm numbers and biomass were higher under QSMAS than under SB (13.4 vs. 0.8 g fresh biomass m−2; respectively). Significant interactions between cropping system and fertilization suggest that QSMAS increased the availability of added inorganic P, 3 times more under QSMAS than for SB. Comparisons with SF, indicated that both cropping systems resulted in a dramatic loss of C (average 5gC kg−1 soil) since treatment implementation, and that this loss was mainly associated with the disruption of C rich large macroaggregates (>2000 µm). After taking into account baseline soil C differences between plots, no major differences in total SOM losses were found between QSMAS and SB management. However, earlier establishment of QSMAS plots suggests that the overall rate of C loss since treatment establishment was lower for QSMAS than for SB. Results from this study suggest that the Quesungual agroforestry system offers great potential to improve soil fertility and biological health in the region relative to traditional slash-and burn agriculture.

Output 2. Soil management practices
Output Target 2009: Alternative production systems like Conservation Agriculture tested and evaluated for effectiveness in maintaining and restoring soil health and with respect to adoptability.

COMPLETED WORK

Quesungual slash and mulch agroforestry system (QSMAS): Improving crop water productivity, food security and resource quality in the sub-humid tropics (Project Final Report).

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Introduction and Justification

Water availability is expected to be one of the main factors limiting food production in the near future. In fact, most agricultural areas on hillsides in developing countries already suffer from seasonal water scarcity and dry spells. The incidence and impact of these events is increasing because of the lack of adequate soil and crop management practices and global climate change. Improving production systems to reduce land degradation while adapting to, as well as contributing for mitigation of, climate change is a major objective in today's agriculture. Particularly challenging is the increase of crop water productivity –the amount of food produced per unit of water invested– in developing countries that depend on rainfed agriculture to feed their growing population.

In south-west Honduras, local farmers and experts from FAO developed a production system named Quesungual. The 'Quesungual Slash and Mulch Agroforestry System' (QSMAS) is a smallholder production system, comprising a group of technologies for the sustainable management of vegetation, water, soil and nutrient resources in drought-prone areas of hillsides in the sub-humid tropics. Initially QSMAS was practiced by over 6,000 resource-poor farmers on 7,000 ha of southwest Honduras, mainly to produce major staples (maize, bean, sorghum). During the last five years, the system has also been adopted in other sub-humid regions of southwest and southeast Honduras, northwest Nicaragua, and Guatemala. This success in improved adoption has been partially driven by QSMAS' substantial contribution to food security, remarkable resilience to natural extremes of water deficit and water excess, and suitability to replace the environmentally unfriendly production systems based on the practice of slash and burn (SB).

The main goal of this project was to use QSMAS to improve livelihoods of rural poor through increased water resources and food security in sub-humid hillside areas, while maintaining the soil and plant genetic resources for future generations. The main objective was to determine the key principles behind the social acceptance and biophysical resilience of QSMAS by defining the role of the management components of the system and QSMAS' capacity to sustain crop production and alleviate water deficits on steeper slopes with high risk of soil erosion.

The specific objectives were: (1) to assess socioeconomic and biophysical context of QSMAS and to systematize information into a database; (2) to define QSMAS management concepts and principles and to develop relevant tools to monitor soil and water quality; (3) to evaluate and document potential areas suitable to QSMAS; and (4) to develop tools for dissemination, adaptation and promotion of the QSMAS management strategies.

Methods

The objectives of this four year project were accomplished by the evaluation of the agronomic and environmental performance of QSMAS compared with the traditional SB system in the reference site of Lempira, Honduras (Apr 2005 to Dec 2007), and in the validation sites of Somotillo, Nicaragua (May 2005 to Dec 2007) and Cauca, Colombia (Aug 2007 to Feb 2008).

The areas of study in the reference site included the water dynamics and crop water productivity, soil losses, nutrient and soil organic matter dynamics, natural vegetation, greenhouse gas and energy fluxes, soil fauna, pests and diseases, and grain yields. In the sites of validation, studies were focused on the adaptation of QSMAS to local conditions and acceptance by farmers and other stakeholders. Other key activities included the analysis of the biophysical and socioeconomic contexts in the reference site, and the generation of extrapolation domains for the adaptation of the system to other suitable regions in the tropics.

Research findings

Results of research activities indicate the following:

- QSMAS can be a model production system embracing principles of conservation agriculture to achieve food security and sustainability in drought-prone areas of the sub-humid tropics.
- In the reference site, the integrated multidisciplinary efforts made to replace the SB system with QSMAS resulted in three biophysical and socioeconomic contexts: (i) the period of high vulnerability when SB system was the predominant source of food; (ii) the period of transition while QSMAS was being developed and disseminated; and (iii) the period of recovery of the landscape and the welfare of the communities as a result of the holistic development strategy that included QSMAS as the main instrument of change.

- QSMAS is an integrated land use management strategy based on four principles that contribute to its superior performance in terms of productivity, sustainability, and biophysical resilience. These key principles are:
  1. *No slash and burn*, through management (partial, selective, and progressive slash-and-prune) of natural vegetation;
  2. *Permanent soil cover*, through continual deposition of biomass from trees, shrubs and weeds, and crop residues;
  3. *Minimal disturbance of soil*, through no tillage, direct seeding, and reduced soil disturbance during other agronomic practices; and
  4. *Efficient use of fertilizer*, through appropriate application (timing, type, amount, location) of fertilizers.
- High natural variation in QSMAS plots (i.e. predominant vegetation, number of trees and shrubs, and soil properties) and marked differences on their management (e.g. crop production and crop residues) demonstrates that the implementation of its principles strongly relies on criteria of individual farmers that are influenced by current and future needs of the householders.
- QSMAS is a suitable option to replace the environmentally unfriendly production systems based on the SB practice, traditionally used by resource-poor small-scale farmers in the Pan tropical world.
- Under experimental conditions, QSMAS is at least as effective as SB system for the production of maize, and more efficient than SB to produce common bean. Undoubtedly, QSMAS performance is favored by management practices leading towards resilience, efficient nutrient cycling, improved crop water productivity, and increased and sustained C synthesis and accumulation. An important effect is the increased availability of soil water in the later part of the bimodal rainy season, when rainfall is usually irregular (dry spells on key stages of crop development) or inadequate (shorter rainy season).
- Compared to SB system QSMAS is not only eco-efficient through the use of renewable natural resources, but also provides ecosystem services including:
  1. *Provisioning services*: <u>food security</u> through improved crop water productivity and yields at lower costs; and <u>improved water cycling</u> through reduced runoff, erosion, water turbidity and surface evaporation, and increased infiltration, soil water storage capacity and use of green water.
  2. *Regulating services*: <u>reduced global warming potential</u> through lower methane emission and improved C accumulation.
  3. *Supporting services*: <u>mitigation of soil degradation</u> through improved structure, biological activity, organic matter, nutrient cycling and fertilizer use efficiency; and restoration and <u>conservation of biodiversity</u>.
  4. *Cultural services*: improved quality of life through the regeneration of the landscape.
- Preliminary analysis on the potential for payment for environmental services (PES) schemes in association with QSMAS showed that adoption of the system has high potential to generate additional sources of income to communities that decide to adopt the system or its principles. Further analysis including the whole watershed is likely to demonstrate even greater environmental benefits and potential for PES, since QSMAS generates important amounts of environmental services at landscape level.
- The driving forces behind QSMAS adoption are multiple and articulated. The success of the system in Honduras is largely the result of a community-based learning process in which local people and extension service providers share ideas and learn together.
- Positive results on validation of the biophysical performance of QSMAS in Nicaragua and Colombia affirm its potential to enhance support for livelihoods in vulnerable rural areas in sub-humid tropics, including on marginal soils on sloping lands. High farmers

awareness of the negative impacts of SB system suggests *that changing to QSMAS may not be difficult since they easily perceive the multiple socioeconomic and biophysical benefits from the system.*

- Extrapolation Domain Analysis (EDA) revealed significant potential suitable areas for adoption of QSMAS - in a number of countries in Latin America, Africa and Asia. However, the results are limited to the availability of data from the reference and target sites in the tropics. Although adoption beyond reference sites is not a simple process to be determined from basic data, the EDA can be used as a means to explore what key factors could induce or restrict wider adoption.

The major outcomes from the project are:

- The acceptance of QSMAS as an alternative to slash and burn agriculture by farmers that validated the system in Nicaragua and Colombia.
- The initiative of INTA to promote QSMAS in other suitable sub-humid areas in Nicaragua(according to a recent study, after four years of validation efforts, around 90% of the 120 farmers in La Danta watershed (where Negro River is born) eliminated burning to manage residues and about 70 of them are already using QSMAS.
- Increased capacity of young professionals in the Mesoamerican region to design and conduct research activities in different topics (agroforestry, farming systems, water and nutrient cycling, soil conservation and climate change, among others).
- Reduced use of inputs in the reference site through improving efficiency in the use of fertilizers by optimizing the timing and amount by splitting the supplementary N application to maize.

The project generated two major outcomes that could potentially contribute towards impacts in the validation area of Nicaragua:

- Increased agricultural productivity and sustainability through the adoption of QSMAS by around 70% of the farmers in the area.
- Sustainable resource management through the reduction of burning (now used by less than 10% of the farmers).
- Acceptance of QSMAS by INTA, Nicaragua to be promoted as a validated technology to replace the SB system in other sub-humid areas.

The international public goods produced by the project include:

- Databases of the experimental data from three PhD and two MSc theses on biophysical factors, and one study on socioeconomics, supported by the project; and of literature pertinent to QSMAS (mainly in Spanish).
- Sixteen theses including four PhD, two MSc and 10 BS, reporting of the methodologies used and the main findings of these studies (most of them in Spanish).
- A document including relevant information of QSMAS, guidelines for the establishment and management of the system, and the potential target regions recommended for its validation based on the EDA.

Recommendations

- Targeting and adapting QSMAS (or its principles of conservation agriculture) to other sub-humid areas will require identification of suitable sites using EDA where QSMAS has the potential to be an alternative to slash and burn agriculture.
- For farmers to fully realize benefits from QSMAS there is need for intensification and diversification of the system by including high value market oriented fruit and vegetable

crops and livestock production, facilitating higher profits while reducing risks and contributing to QSMAS' sustainability.

- Policy implications for achieving wider impacts of QSMAS include introduction of: (i) regional-national-local goals to improving sustainability of agroecosystems while enhancing their functionality; (ii) local agricultural and developmental extension systems: (iii) incentives to communities to adopt more sustainable and environmentally friendly production practices; (iv) financial mechanisms to facilitate adoption of proposed changes; (v) improved infrastructure to sustain productivity gains (such as silos); and (vi) payment for environmental services (PES) schemes.
- Potential PES provided by QSMAS (or other forms of conservation agriculture) at plot and landscape level may enhance its attractiveness to local and national authorities in countries with policies to protect ecosystems in the face of climate change, and persuade communities towards its adoption for the sustainable management of natural resources.
- The need for further research on QSMAS includes:
    1. *Filling knowledge gaps at system level:* increase of crop water productivity; resilience and profitability when integrated with livestock and fruit trees; contribution as part of a farming system (small scale) or as part of a multifunctional landscape (large scale); and potential to recover degraded soils.
    2. *Strategies for scaling up and scaling out of QSMAS:* validation-dissemination (linked to capacity building) in similar sites in the tropics; development of drought insurance linked with the use of the system; and assessment of the potential for PES at the landscape level linked to the use of QSMAS.
    3. *Generation of PES* schemes for improving landscape function for services related to water, C sequestration and mitigation of greenhouse gas emissions, soil quality and resilience (even to natural disasters), conservation of biodiversity, recovery of degraded soils, and ecotourism.

Tillage, residue management and fertilize application effects on crop water productivity in western Kenya

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Abstract: A long-term conservation tillage experiment was established in Nyabeda, Western Kenya in March 2003 to investigate the effects of tillage and residue management on crop water productivity (CWP, kg grain m-3 rain) in continuous maize and maize-legume cropping systems. Seasonal CWP of maize over the first eight cropping seasons ranged frp, 0.1 to 0.8 kg m-3 of in-season rainfall. For continuous maize, there was a consistent trend for lower CWP with reduced tillage (RT) compared to conventional tillage (CT) for the first few years, for respective residue retained/removed treatments, but with no significant differences. After five seasons, CWP was similar with RT and CT, with and without crop residues (CR). There was also a consistent trend for higher CWP or RT with CR than without CR for the first 5 seasons, but with no significant differences. Similar trends in maize CWP occurred in the maize-legume rotation, except in the first year where CR led to reduced yields, presumably due to N immobilization as N fertilizer was applied. CWP of soybean was not affected by tillage treatment or residue management. With low rainfall, crop residue (CR) application increased yield buy p to 30% under RT. The yield advantage of CR (over no CR) decreased with increasing rainfall ($R2 = 0.9$ for continuous maize and $R2 = 0.7$ for soybean-

maize rotation). CR disappearance was fast (daily % loss of 106 $e^{-0.019x}$). Phosphorus (P) and nitrogen (N) application had large effects on CWP. In the maize-soybean rotation, P application increased CWP of maize by 120%, while application of N with P increased CWP by a further 35%. Thus fertilizer application is important for increased CWP. The results suggest that RT with mulching gives similar maize CWP in continuous maize and maize-legume rotations. Rotation with soybean brings further benefits including reduced N fertilizer requirement, while soybean CWP is also maintained in the RT.

Competing use of organic resources, climate variability and village-level interactions in a communal area of NE Zimbabwe

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Abstract: Addition of organic materials is needed to sustain agricultural production on inherently poor soils. 22 In communal areas of NE Zimbabwe, livestock feed resources are collectively managed, with herds 23 grazing on grasslands during the rainy season and mainly crop residues during the dry season, 24 which creates interactions between livestock and non-livestock owners, including competition for 25 organic resources. This study explored such interactions quantifying nutrient flows and long-term 26 effects of management on soil productivity. Crop and cattle management data collected in Murewa 27 Communal area in NE Zimbabwe was used to test and adapt a dynamic farm-scale simulation 28 model (NUANCES-FARMSIM) to simulate village level interactions. Simulations showed that 29 grasslands support most of livestock feed intake for all the herds (c. 75%), and that crop residues 30 produced by non-livestock owners sustained about 30% of the intake during the dry season. The 31 removal of crop residues (0.3−0.4 t C ha−1yr−1) from fields of non-livestock owners resulted in a 32 long-term decrease on crop yields. Impeding access of cattle to crop residues of non-livestock 33 owners increased soil C contents modestly and improved yields in the mid- to long-term, but not 34 enough to meet energy requirements of the household.

The herd of the village with an average size 35 of 187 cattle transferred 100 t faecal dry matter per year from grassland to cropland. With 36 minimum losses, that amount will not suffice to manure 10% of the 116 ha of cropland at the 37 recommended rates of 10 t ha-1 per year. Due to poor manure management, only 8−32 kg manure N 38 ha-1 per year were available to be applied to crops, with N losses of 70 to 80% between excretion 39 and application to the fields. Due to harvest of grain and removal of most crop residues by grazing 40 cattle, there was a decline in soil C stocks for all farm types over the simulation period of 10 years. 41 The smallest decrease (−0.5 t C ha−1) was observed for most fertile fields of the livestock owners 42 who compensated for C losses through manuring fields. Without considering overgrazing, 43 wealthier farmers owning 10 cattle heads need to access 12−27 ha of grassland to apply about 3−4 t 44 of manure per year in their 3 ha farms. Increasing amounts of mineral fertilisers used concurrently 45 with keeping crop residues in fertile fields and allocating manure to the poor fields, appears to be a 46 promising strategy to boost crop productivity at village level. The likelihood of this scenario being 47 implemented depends on availability of fertilisers and decision of farmers to invest in rehabilitating 48

soils to obtain benefits in the long-term, as opposed to concentrating all organic inputs in small 49 areas and creating islands of fertility where crop yields are secured.

Decreasing fallow duration in tropical slash-and-burn agriculture alters soil macro invertebrate diversity: A case study in southern French Guiana *(2009) Agriculture ecosystems and environment 135, 148-154*

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Abstract: In the humid tropics, slash-and-burn cultivation causes changes in the composition of soil biota communities. We investigated the soil macroinvertebrates (body length >= 2 mm) in five sites, two at Maripasoula, an Aluku village along the Maroni river (French Guiana), with short fallow (approximate to 8 years), and the other three at Elahe, a Wayana village along the same river, with long fallow (approximate to 25 years). We report observed species richness, the corresponding estimates by bootstrap and its associated standard deviation. At both sites the cultivation led to impoverished communities. The overall observed species richness Le. gamma diversity was twice as larger in Elahe than in Maripasoula. The landscape at Maripasoula was dominated by highly disturbed areas with the direct consequence that local species richness relied on colonization from an impoverished regional species pool. On the contrary, in Elahe, crops formed small patches scattered across a landscape essentially constituted of rich undisturbed or slightly disturbed forests hence higher gamma diversity. The proportion of rare species ranged from 44% to 54%. We found 6 indicator species amongst which 5 were associated to the old secondary forest in Elahe and one, the earthworm Pontoscolex corethrurus was associated to crop fields in Maripasoula (short fallow system). Results are discussed in a landscape context in terms of conservation and management of soil macrofaunal diversity in agro-ecosystems.

Cotton expansion and biodiversity loss in African savannahs, opportunities and challenges for conservation agriculture: a review paper based on two case studies *(2009) Biodiversity and conservation, 18 (10): 2625-2644.*

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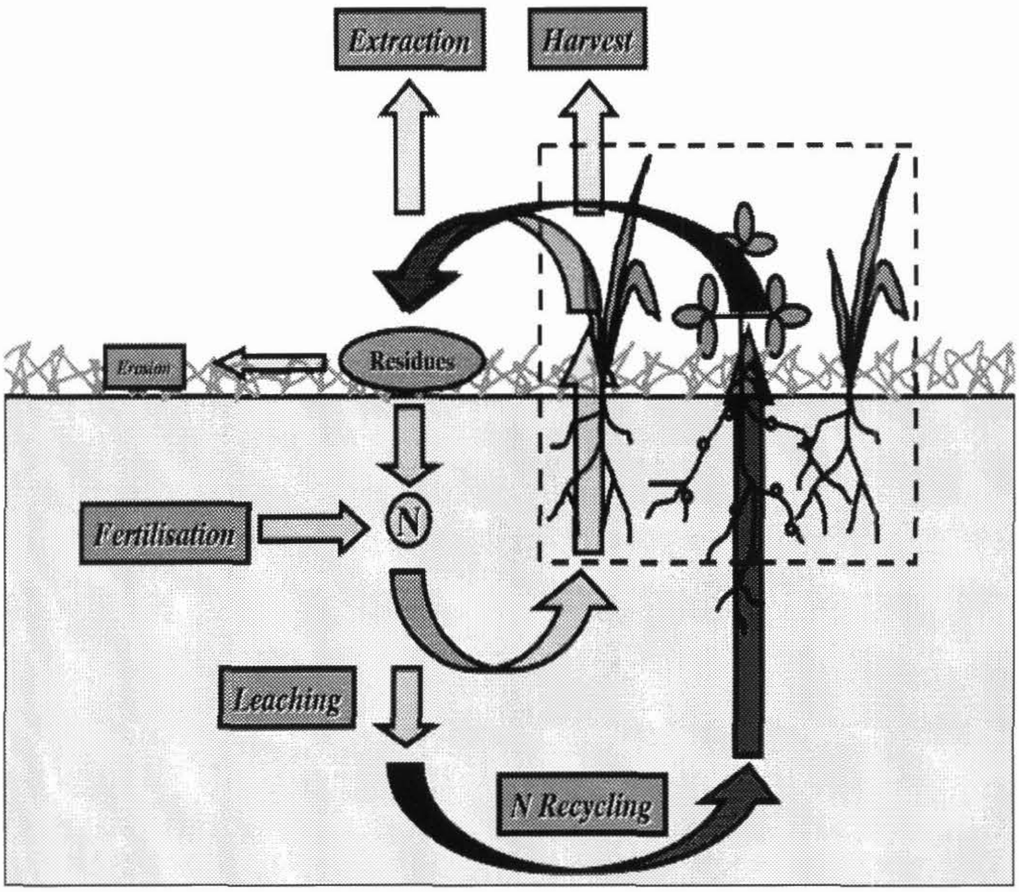
Abstract: We review agricultural impacts on biodiversity and the potential of conservation agriculture in developing productive and environment-friendly cropping systems. We then analyse experiences from two African landscapes of global importance for conservation: the Mid Zambezi Valley in Southern Africa and the periphery of the ''W-Arly-Penjari'' complex in West Africa. In both areas, expansion of cotton farming, considered as one of the most polluting forms of agriculture in the world, drives major land use change and loss of biodiversity. In both areas, various forms of conservation agriculture have been developed and tested. We highlight the potential benefit of conservation agriculture in controlling negative environmental effects traditionally associated with agriculture and reducing the need for land conversion through increased biophysical resource use efficiency, turning agriculture

from a threat to an opportunity for conservation. Finally, we raise a number of issues that constitute challenges for the widespread adoption of these technologies by resource-poor farmers, and formulate recommendations for the development, evaluation and diffusion of conservation agriculture technologies for smallholders in semi-arid Africa.



Association of a deep-rooted crop ("cover crop") to the main crop in a conservation agriculture system, to recycle nutrients and increase biomass production.

WORK IN PROGRESS

Does conservation agriculture mitigate the negative effects of climatic change on crop production: a modelling analysis for a case study in Zimbabwe

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Introduction

Conservation agriculture (CA) is seen as a new paradigm to conventional agriculture that uses soil tillage. Three practices underpin CA: (1) minimizing soil disturbance by reduced or zero-tillage; (2) retaining residues on the soil surface and (3) using crop rotations. There is a consensus among climate specialists that Southern African regions will become dryer with more irregular rainfall over by the end of the 21st century. In the global context, maize in Southern Africa is seen as one of the most important crops in need of adaptation investment. Can CA mitigate these negative effects of climate change on crop production? It is known that the water conserving effect of CA practices can stabilize crop yields under drought conditions, but the same effect exacerbates poor drainage. We developed a simulation modelling approach to better understand the potential role of CA under changing rainfall patterns. We present in this paper the results for a case study in Zimbabwe.

Material and methods

The crop growth model DSSAT-CSM (Jones et al., 2003) was adapted to simulate CA practices, and then calibrated and tested using data from a soil tillage experiment at the Henderson Research Station (17°35' S, 30°38'E, 1136 m.a.s.l.) near Harare in Zimbabwe. The region is characterized by a sub humid subtropical climate with an average annual rainfall of about 880 mm. Rain falls during summer from November until early April. Average annual temperature is about 22°C. The site has a slope of about 5 to 7 % and the soil was classified as a dystric Arenosols. For this study, 2 tillage treatments were considered: (1) the conventional farmer's practice of ploughing the soil to a shallow depth (10 to 15 cm) without retention of crop residues (CT); (2) the no-tillage practice with retention of crop residues (about 2 ton DM/ha) using a direct seeder (CA).

DSSAT-CSM uses daily weather, crop and soil parameters as input to predict growth and yield of a range of crops. Model adaptations included the influence of crop residue cover and tillage on soil surface properties and the soil water balance. With the model we assumed that the following four soil properties vary with tillage: 1) bulk density, 2) saturated hydraulic conductivity, 3) the 'Soil Conservation Service' runoff curve number and 4) soil water content at saturation. The soil properties after a tillage event are input and they change back to a settled value, following an exponential curve that is a function of cumulative kinetic energy since the last tillage operation (Andales et al, 2000). A mulch of crop residues affects three soil water-related processes in the model: 1) rainfall interception by the mulch, 2) reduction of soil evaporation rates, and 3) reduction of surface water runoff.

We ran the model to simulate maize production for water-limited conditions under the present climate using 45 years of daily climatic data (baseline scenario, BS) from Harare and under three plausible future rainfall scenarios for the region (Lobell et al., 2008). These were: (1) a 15% decrease in annual rainfall, RS; (2) a 15% increase in the duration of dry spells, DS; and (3) the combination of scenarios 1 and 2, RDS. Each scenario also comprised a temperature increase of 1.1°C. The scenarios were constructed using the stochastic weather generator LARS-WG (Semenov and Barrow, 1997)

Preliminary results

Using DSSAT-CSM we predicted water-limited maize grain yield for the Henderson site under the 4 weather scenarios (including the baseline climate) and for the 2 tillage treatments (CT and CA). Planting date was during the last week of October. For the baseline scenario (BS) simulated maize grain yield was on average about 720 kg/ha higher under CA then under CT **(Table 1)**. This was mainly due to increased water availability as a result of decreased runoff under CA compared to CT. Predicted yields varied broadly, from a minimum of 1003 kg/ha to a maximum of 6483 kg/ha depending on seasonal rainfall amount and distribution. As expected average grain yields for both tillage practices were lower for future climate scenarios **(Table 1)**. The simulation results indicate that the impact of a 15% increase in the duration of seasonal dry spells (DS scenario) is at least as large as that of a 15% decrease in annual rainfall (RS scenario). Under the RDS scenario of decreased rainfall with longer dry spells model predictions suggest a decrease in maize grain yields of about 25 to 30%, which is in agreement with the value (30%) projected for Southern Africa in a broad-scale analysis by Lobell et al (2008). The cumulative distribution functions of simulated maize grain yield for the BS and RDS climate scenarios under CT and CA are presented in **(Figure 10)**. Under the current climate the probability of producing at least 3000 kg/ha grains is 41 and 67 % for respectively CT and CA. Under future climate, due to water stress the probability drops to respectively 15 and 43%. The results indicate that the negative impact of climate change can be mitigated by adopting CA in the 'normal' years, but with a higher risk of lower yields in the 'good' and 'bad' years.

Table 1: Effect of climate change on maize yield (kg/ha) as simulated by DSSAT-CSM under conventional *tillage* and CA for the Henderson site nearby Harare, Zimbabwe. Variation coefficient in parenthesis

	BS	RS	DS	RDS
CT	3107 (0.39)	2607 (0.35)	2577 (0.41)	2254 (0.43)°
CA	3830 (0.35)	3166 (0.34)	3328 (0.37)	2832 (0.40)

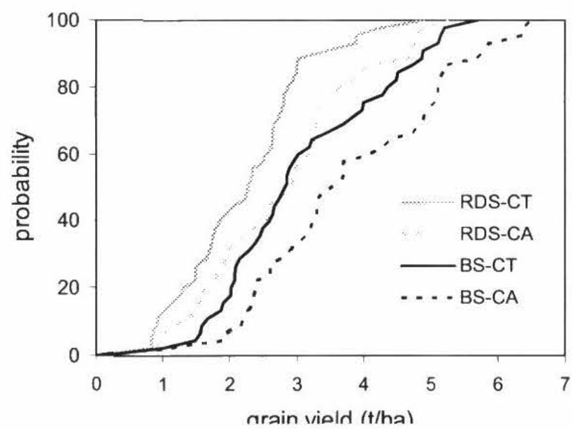

Figure 10: Cumulative probability functions of maize grain yield as simulated by DSSAT-CSM for the BS and RDS climate scenarios under CT and CA practices.

Preliminary conclusions

The simulation results show that climate change will have a major impact on maize productivity in the study region. CA practices have a potential to reduce climatic risk for farmers in southern Africa. However, the question remains how these practices fit in their farming systems. Crop residue mulching profoundly alters the flow of resources at the farm, and there are trade-offs in the use of crop residues at farm level. Crop residues, and in particular cereal stover, is a highly-valued fodder for livestock in smallholder farming systems in Africa.

Influence of conservation tillage on soil microbial diversity, structure and crop yields in sub-humid and semi-arid environments in Kenya

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Introduction

Conservation tillage approaches affect soil microbial populations, soil structure and crop performance but the effects within African climate and soil conditions are not well understood. Tillage is known to affect soil aggregation through disruption of macro-aggregates and increased turnover rate of organic resources. In many small-holder farming systems in Africa, crop residue after harvest is either left on the farm as a strategy for soil fertility management or removed to serve varied uses: fodder, fuel etc. We investigated how maize stover retained within the cropping systems affects soil aggregation under conventional and reduced tillage systems. The stover is usually of lower quality than legume residues and their interaction could lead to aggregation differences between cropping systems where legume is included, and those planted with cereal only. In most sub-Saharan Africa, intercropping is the most predominant cropping system within small holder farming systems. However, works reported in literature focus mainly on pure crop stands either in rotation or continuous monocropping with a one-time per season application of some external organic resource. By affecting composition and structure of organic matter (Agnelli et al. 2004), cropping systems could in-turn affect microbial diversity through variability in nutrient and energy sources. In this study therefore we investigated the effect of conservation tillage practices, organic resource application and cropping systems on soil microbial diversity, soil structure and crop yields.

Materials and methods

This study was conducted in two agro-ecological zones; a semi-arid zone (Machang'a in eastern Kenya) and sub-humid zone (Matayos and Nyabeda in western Kenya). The experiment in the semi-arid site was a randomized complete block design with 3 tillage systems (conventional tillage, no-till and tied-ridging) each with two organic applications (2 t ha/ manure applied alone and, 1 t/ha manure plus 1 t/ha crop residue). The experiments in the two sub-humid sites were designed as split-split plots with tillage (conventional and reduced tillage), crop residue (0 and 2 t/ha maize stover) and cropping systems (continuous maize, maize soybean intercropping and rotation) as the main, split and split-split plots respectively. Conventional tillage involved hand hoeing to about 10-15cm depth as done by small-scale farmers, 3 times per season. Tied-ridges were prepared during trial initiation and maintained throughout the experiment, with tillage restricted to refreshment of the ridges. In the no-tillage system, land preparation was done using hand hoes and only hand pulling of weeds in between the season. Under reduced tillage, hoeing was restricted to surface scratching to 3cm depth to remove weeds. Average crop yield data for the first 3, 4 and 8 seasons in Matayos, Machang'a and Nyabeda, respectively, is reported. Soil sampling for microbial analysis and aggregation determination was done during 4th, 5th and 10th seasons in Machang'a, Matayos and Nyabeda, respectively. Aggregation sampling depths were 0-15cm for Machang'a and 0-

20cm for Nyabeda and aggregate separation was by wet sieving using a series of 3 sieves (2mm, 250μm and 53μm). Isolation of POM, silt-clay and micro-aggregates within macro-aggregates was done according to the procedure of (Six et al. 2000). Bacteria and fungal diversity were determined from dry-incubated soils for Matayos and Machang'a and fresh soil for Nyabeda, using PCR-DGGE techniques.

Preliminary results

Conservation tillage systems could have similar or lower yields compared to conventional tillage systems. We observed similar yields between Tied-ridge and conventional tillage over 4 cropping seasons in Machang'a, but significantly lower yields in reduced and no-tillage systems **(Table 2)**. In the dryland site also, although no-till yields were lower than conventional system for the initial seasons, they increased progressively and were significantly higher by the fourth season (data not shown). Application of crop residue increased yields by 13% in Matayos and 15% Nyabeda while combination of manure and CR in Machang'a increased yields by 24% over manure only treatments **(Table 2)**. CR is important also in soil water conservation and regulation of soil temperature especially when applied as surface mulch, as often done in reduced tillage. Recently, in order to improve water relations and crop performance in no-till and reduced tillage systems, modifications have emerged including ripping and sub-soiling and the results are promising (Motavalli et al. 2003), but also depending on the rainfall regime.

We also observed the effect of crop residue on yield to vary with tillage and application of inorganic N; application of CR suppressed yields in conventional tillage especially when N was not applied indicating soil inorganic N immobilization, but up to 30% yield increases attributable to crop residue were observed under reduced tillage (data not shown). Reduced and no-till farming can be effective in enhancing soil macro-aggregation. In both sites where aggregate separation was done (Machang'a and Nyabeda), higher aggregation was observed in conserved plots compared to conventionally tilled ones. This demonstrates that avoiding soil disturbance is necessary to improve aggregation of both clay and sandy soils. Although no significant effect of organic resource application on aggregation was observed over the overall soil depths, there was positive effect with combination of manure and crop residue in Machang'a increasing aggregation index by 17% over manure only treatments. And we also observed significant crop residue effect on soil aggregation at the surface 0-5cm soil layer, the zone where much of the CR was located (data not shown) showing that managing soil organic matter remains of great importance for the structural stability of the very surface soil. Among the cropping systems, intercropping had higher aggregation indices compared to the rotation system, but similar with continuous cereal system (data not shown). Continuous presence of a legume in the intercropping system could favour stability or re-formation of macro-aggregates via its root residues and legume organic exudates, its associated microbial community or simply the effect of its higher plant density (maize plus soybean) relative to the other systems. However, under rotation, the macro-aggregates formed during the legume phase likely break up after the legume crop is removed, leading to increased micro-aggregates and silt and clay fractions and hence lower aggregate mean diameter.

Diversity of bacteria is affected by tillage and organic substrates of different sources (Øvreås and Torsvik 1998). Diversity of bacteria in Machang'a and Nyabeda were not affected by tillage but in Matayos, reduced tillage showed higher bacteria diversity over conventional tillage system. Fungi diversity was higher in CT than in RT but nevertheless, we found no difference in the numbers of identified bands. Higher band volume under reduced tillage indicated that few fungal communities dominated this system, leading to the lower Shannon diversity index observed. Also there was significantly low diversity of fungal where crop residue was applied compared to treatments without crop residue, again due to domination by fewer species. Shannon diversity is high only when species numbers are high and evenness fulfilled. It could also be that domination by few species of fungi pushes other existing species to the <1% of microbial cells, usually too few to be detected by PCR-DGGE technique. As observed with soil aggregation, both bacteria and fungi diversity (Shannon index) were higher in intercropping compared to continuous maize system as observed in Nyabeda (data not shown). In Machang'a despite low carbon content, bacteria diversity was higher than in Matayos perhaps due to the towards neutral pH compared to more acidic soils in Matayos. In a continental-scale research involving different sites in North and South America, diversity of soil bacteria communities increased as soil pH increased from acidic to near neutral (Fierer and Jackson 2006).

Table 2: Effect of tillage on maize grain yield, aggregate mean weight diameter and microbial diversity

Site	Tillage	Maize grain yield (t ha-1)	Aggregate MWD	Bacteria diversity (H')	Fungi
Matayos	RT	1.44 [a]	-	2.05 [b]	-
CT		2.01 [b]	-	1.79 [a]	-
SE		*0.186*	-	*0.085*	-
Nyabeda	RT	3.15 [a]	1.81 [b]	2.02 [a]	1.56 [a]
CT		3.71 [b]	1.47 [a]	2.04 [a]	1.67 [a]
SE		*0.156*	*0.080*	*0.075*	*0.057*
Machang'a	NT	1.74 [a]	0.80 [b]	2.11 [a]	-
TR		2.08 [ab]	0.74 [ab]	2.10 [a]	-
CT		2.30 [b]	0.60 [a]	2.11 [a]	-
SE		*0.124*	*0.053*	*0.090*	-

Output 2. Soil management practices	
Output Targets 2010	Alternative crops and integrated systems investigated for their effectiveness in maintaining soils resource base.
	The role of soil organic matter in regulating BGBD and soil health tested across a number of experimental sites in at least 5 countries in the tropics
	Species/strains identified with potential for inoculants development; Direct inoculation in various cropping systems and for various purposes (enhancing productivity, control of soil borne pest and diseases and improving soil structure) tested on persistence, affectivity and competitiveness.

Much of the output targets for 2010 are similar to outputs target for 2009 and allow for the reporting on continuous work done in this field. More specific outputs relate to the identification of species and strains with potential for inoculants production that is looking at the genetic diversity and looking at strains with genetic beneficial traits. In some of CSM-BGBD work we are actually looking at effectiveness of certain strains (of nitrogen fixing bacteria and AMF) sourced from the benchmark areas where the BGBD inventory has been done. The results of this are not expected until 2010. Other work like testing commercial inoculum products of various kinds (Trichoderma, nitrogen fixers, etc.) is done under the umbrella of the ISFM research program.

COMPLETED WORK

Adoption potential of selected organic resources for improving soil fertility in the central highlighands of Kenya

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Abstract: Soil fertility decline is the major cause of declining crop yields in the central highlands of Kenya and elsewhere within the African continent. This paper reports a study conducted to assess adoption potential of two leguminous trees, two herbaceous legumes, cattle manure, and *Tithonia diversifolia* either solely applied or combined with inorganic fertilizer, for replenishing soil fertility in the central highlands of Kenya. The study examined biophysical performance, profitability, feasibility and acceptability, and farmers experiences in managing and testing the inputs. The study was based on a series of studies incorporating both sociological and experimental approaches for two and a half years. Results of on farm trials showed that manure + fertilizer and tithonia + fertilizer treatments increased yields by more than 100% above the control. These treatments were the most profitable having highest net benefits and benefit cost ratios. They were also the most commonly preferred by farmers who used them on larger plots compared to the other inputs. In conclusion, cattle manure and tithonia were found to be the organic materials with the highest adoption potential for soil fertility improvement in this area. *Calliandra calothyrsus* and *Leucaena trichandra*, on the other hand, have potential for use as animal fodder. The herbaceous legumes had the least adoption potential due to poor performance recorded on the farms that possibly led to low preference by the farmers. However, issues of sustainable seed production could have played a role. This study recommends some policy issues for enhancing adoption and research issues focusing on exploring strategies for increasing biomass production and use efficiency on farms.

An integrated evaluation of strategies for enhancing productivity and profitability of resource-constrained smallholder farms in Zimbabwe

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Abstract: In African smallholder agriculture, improved farm-scale understanding of the interaction between the household, crops, soils and livestock is required to develop

appropriate strategies for improving productivity. A combination of models was used to analyse land use and labour allocation strategies for optimizing income for wealthy (2.5 ha with eight cattle) and poor (0.9 ha without cattle) farms in Murewa, Zimbabwe. Trade-offs between profitability, labour use and partial nutrient balances were also evaluated for alternative resource management strategies. Farm data were captured using the Integrated Modelling Platform for Mixed Animal-Crop Systems (IMPACT), which was directly linked to the Household Resource use Optimization Model (HROM). HROM was applied to optimize net cash income within the constraints specific to the households. Effects of alternative nutrient resource management strategies in crop and milk production were simulated using the Agricultural Production Systems Simulator (APSIM) and RUMINANT models, respectively, and the output evaluated using HROM. The poor farm had a net income of US$ 1 yr1 and the farmer relied on selling unskilled labour to supplement her income. The poor farm's income was marginally increased by US$18 yr1 and the soil nitrogen (N) balance was increased from 6 to 9kg ha1 yr1 by expanding groundnut production from the previous 5–25% of the land area. Further increases in area allocated to groundnut production were constrained by lack of labour. On the poor farm, maize production was most profitable when cultivated on a reduced land area with optimal weeding. The wealthy farm had a maize-dominated cropping system that yielded a net cash balance of US$290 yr1, mainly from the sale of crop produce. Net income could be increased to US$1175 yr1, by re-allocating the 240 hired labour-days more efficiently, although this reallocation substantially reduced partial soil N and phosphorus (P) balances by 74 kg N ha1and11kg Pha1, respectively, resulting in negative nutrient balances. Few opportunities existed to increase productivity and income of the smallholder farms without inducing negative nutrient balances. On the wealthy farm, groundnut was the least profitable crop; shifting its production to the most fertile field did not improve income unless the groundnut residues were fed to lactating cows. The analysis carried out in this paper highlights the need to develop practical technological recommendations and development interventions that consider farm resource endowment (land, fertilizers, manure and labour), variability in soil fertility within farms and competing resource use options.

Managing soil fertility diversity to enhance resource use efficiencies in smallholder farming systems: a case from Murewa District, Zimbabwe

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Abstract: Sub-Saharan African smallholder farms exhibit substantial differences in soil fertility, and nutrient resource allocation strategies appropriate for plots differing in fertility are required to increase nutrient use efficiencies. We applied the Field-scale resource Interactions, use Efficiencies and Long term soil fertility Development (FIELD) model to explore consequences of various manure and fertilizer application strategies on crop productivity and soil organic carbon (SOC) dynamics on farms varying in resource endowment in a case study village in Murewa District, Zimbabwe. FIELD simulated a rapid decline in SOC and maize yields when native woodlands were cleared for maize cultivation without fertilizer inputs coupled with removal of crop residues. Applications of >10 t manure ha^{-1} yr^{-1} for 10 years were required to restore maize productivity to the yields attainable under native woodland. Long-term application of manure at 5 and 3 t ha^{-1} resulted in SOC contents comparable to zones of high and medium soil fertility observed on farms of wealthy

cattle owners. Targeting manure application to restore SOC to 50-60% of contents under native woodlands was sufficient to increase productivity to 90% of attainable yields. Short-term increases in crop productivity achieved by reallocating manure to less fertile fields were short-lived on sandy soils. Preventing degradation of the soils under intensive cultivation is difficult, particularly in low input farming systems, and attention should be paid to judicious use of the limited nutrient resources to maintain a degree of soil fertility that supports good crop response to fertilizer application.

Simulation of soil organic carbon response at forest-cultivation sequences using ^{13}C measurements.

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There are few long-term experiments that have used the ^{13}C isotope technique to study the impact of clearing native vegetation for arable cropping on SOC dynamics. This study data from four chronosequence sites was used to evaluate the ROTHC model. The long-term response of SOC to forest clearance is therefore not represented by a single set of measurements from long-term sites but instead from measurements of plots with similar soil and management characteristic but of different cropping ages. To account for the inaccuracies for substitution of time for space, an uncertainty analysis was carried out to estimate the variability in model results. The objectives of this study were to (i) evaluate ROTHC at forest-cultivation sequence sites using ^{13}C abundance measurements, (ii) assess the reliability of the model results due to uncertainties in the input data, (iii) to use ^{13}C natural abundance in conjunction with soil fractionation to evaluate the dynamics of the C pools of ROTHC separately from total C dynamics, (iv) account for soil erosion and (v) implement a simple approach to simulate the dynamics of physically protected C.

While ROTHC accurately predicted the accumulation of maize derived C, it failed to accurately capture the fast decrease in forest C that occurs during the first years of cultivation. However, when the forest and arable soils are at steady-state, the calculated input of plant C to the soil compared well with plant input values obtained from estimates of NPP. This suggested that the model provides good estimates of plant organic matter inputs. Results were in good agreement with recent studies on SOM dynamics that have focused on the biological and physiochemical processes and control of SOM stabilisation and turnover. Our simple approach agrees with the conceptual model of soil C stabilization. The study has further shown that the combination of ^{13}C abundance with SOM particle-size fractionation techniques is an excellent tool to evaluate the performance of a SOM model under land use change conditions.

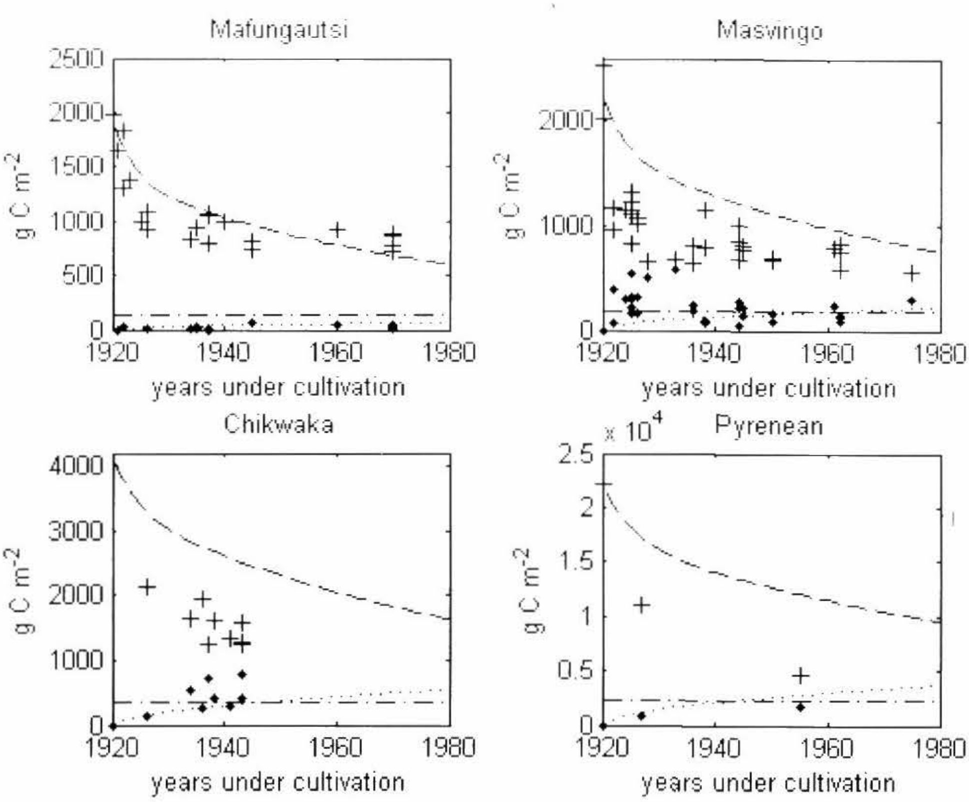

Figure 11: Forest derived C (crosses) and maize derived C (squares) and *simulated* forest derived C (dashed line) and maize derived C (dotted line) for four chronosequence sites in Zimbabwe. IOM pool calculated using the model default Falloon equation (dashed-dotted line).

Output 2. Soil management practices	
Output Targets for 2011	Tools for modeling resource allocation within agricultural productions landscapes and optimization of resource reallocation suggested for selected agricultural production landscapes.
	Improved production systems (including technologies) and having multiple benefits of food security, income, human health and environmental services documented and characterized in terms of application domains.

COMPLETED WORK

Communicating complexity: Integrated assessment of trade-offs within African farming systems to support development policy

Giller[1], K.E., Tittonell[2], P., Rufino[1], M.C., van Wijk[1], M.T., Zingore[3], S., Mapfumo[4], P., Adjei-Nsiah[5], S., Herrero, M., Chikowo[4], R., Corbeels[2], M., Pacini, C., de Ridder[1], N., Smith, J., Karanja, S., Quiroz, C., K'ungu, J., Baijukya, F., Kaizzi, C., Mwale, M., Nwaga, D., Sanogo, O.M., van de Burg, J., Yeboah, E., Rowe, E. and Vanlauwe B.

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Abstract: African farming systems are highly heterogeneous: between agroecological and socioeconomic environments, in the wide variability in farmers' resource endowments and in farm management. This means that single solutions (or 'silver bullets') do not exist. Yet to date approaches to understand constraints and explore options for change have not been available to find a way through the – seemingly bewildering – complexity of African farming systems. In this paper we describe the NUANCES framework. NUANCES offers a structured approach to unravel and understand the complexity of African farming to identify what we term 'best-fit' technologies – technologies targeted to specific types of farmers and to specific niches within their farms. The NUANCES framework is not 'just another computer model'! We combine the tools of systems analysis and experimentation, detailed field observations and surveys, incorporate expert knowledge (local knowledge and results of research), generate databases, and apply simulation models to analyse performance of farms, and the impacts of introducing new technologies. We have analysed and described complexity of farming systems, their external drivers and some of the mechanisms that result in (in) efficient use of scarce resources. Attempts to standardize data collection for characterisation of farming systems did not work due to the large differences between locations. However, farm typologies appear to be useful to target technologies between farmers of different production objectives and resource endowment (notably in terms of land, labour and capacity for investment).

Soil fertility gradients: what did we learn about targeting nutrients and possibilities to re-habilitate soils? Type of fields: responsive vs non-responsive?
Nutrient cycling through livestock, is in principle not efficient for increasing food production but attractive if it generates cash daily. A particular problem farmers face is how to rehabilitate degraded soils. Our analyses show that rehabilitation of soils takes considerable time and capital investment often beyond the reach of rural households. However, investing on soil fertility helps improving food self-sufficiency in the long-term, and there is a clear trade-off between income generation and soil conservation. Technology targeting at farm level is mainly constrained by poor availability of resources, and driven by farmers objectives. In crop-livestock systems, individual objectives have often to match community agreements and demands. Although our analyses indicate that farmers often are doing the best they can with available resources, we find that farmers often lack a good understanding of how best to manage resources when they become available. These examples show that future analyses must focus at the farming system and farm levels to achieve appropriate targeting of technologies – both between locations and between farms at any given location. The approach for integrated assessment described here can be used *ex ante* to explore the potential of best-fit technologies the ways they can be best combined at farm level. We intend to test the NUANCES approach for out-scaling of best-fits.

FIELD-A summary simulation model of the soil–crop system to analyse Long-term resource interactions and use efficiencies at farm scale.

European journal of agronomy, 32 (1): 10-21.

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Abstract: Resources for crop production are often scarce in smallholder farming systems in the tropics, particularly in sub-Saharan Africa (SSA). Decisions on the allocation of such resources are often made at farm rather than at field plot scale. To handle the uncertainty caused by both lack of data and imperfect knowledge inherent to these agricultural systems, we developed a dynamic summary model of the soil–crop system that captures essential interactions determining the short- and long-term crop productivity, while keeping a degree of simplicity that allows its parameterisation, use and dissemination in the tropics. Generic, summary functions describing crop productivity may suffice for addressing questions concerning tradeoffs on resource allocation at farm scale. Such functions can be derived from empirical (historical) data or, when they involve potential or water-limited crop yields, can be generated using process-based, detailed crop simulation models. This paper describes the approach to simulating crop productivity implemented in the model FIELD (Field-scale Interactions, use Efficiencies and Long-Term soil fertility Development), based on the availability of light, water, nitrogen, phosphorus and potassium, and the interactions between these factors. We describe how these interactions are simulated and use examples from case studies in African farming systems to illustrate the use of detailed crop models to generate summary functions and the ability of FIELD to capture long-term trends in soil C and crop yields, crop responses to applied nutrients across heterogeneous smallholder farms and the implications of overlooking the effects of *intra*-seasonal rainfall variability in the model. An example is presented that evaluates the sensitivity of the model to resource allocation decisions when operating (linked to livestock and household models) at farm scale. Further, we discuss the assessment of model performance, going beyond the calculation of simple statistics to compare simulated and observed results to include broader criteria such as model applicability. In data-scarce environments such as SSA, uncertainty in parameter values constrains the performance of detailed process-based models, often forcing model users to 'guess' (or set to default values) parameters that are seldom measured in practice. The choice of model depends on its suitability and appropriateness to analyse the relevant scale for the question addressed. Simpler yet dynamic models of the various subsystems (crop, soil, livestock, manure) may prove more robust than detailed, process-based models when analysing farm scale questions on system design and resource allocation in SSA.

III.3. OUTPUT 3 - SOCIO-ECONOMIC AND CULTURAL DRIVERS FOR LAND DEGRADATION IDENTIFIED AND CONSTRAINTS FOR SLM MAPPED; INTERVENTION DOMAINS FOR SUSTAINABLE LAND MANAGEMENT AND RESTORATION OF DEGRADED LAND IDENTIFIED

Outputs (Intended users)	Outcome (Impact)
Description: Socio-economic and cultural drivers for land degradation identified and constraints mapped; Options for sustainable land management and reversal of soil degradation for social profitability developed and application domains identified. Intended users: intended users: CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers.	Outcome & Impact: Improved diagnosis of soil health problems informs identification of entry points and targeting of soil and land management interventions.

In the current MTP a separate output was defined for the socio-economic drivers of land degradation and constraints for improving soil and land health. To some extent this could be included under output 1, the study of processes of land degradation and output 2 that looks into management options. This output is not maintained as separate output for the next MTP. However, there is some merit in having this as a separate output to be ale to address more specifically economic constraints and look into the social aspects of land degradation as well as technology adoption. Stewardship of the land and the environment is not something that a farmer carries out in isolation but is a social and communal responsibility. Therefore social organization becomes an important element to look at. The role of innovation platforms, as a way to involve farmers more directly in research and as a way to link research to development as well as linking farmers to markets, is an import research topic.
Even more so is the question of intervention domains relevant. That is, who should intervene, at what scale the intervention should take place, who should be targeted and how (what are the entry points), such that we have maximum adoption, returns to investment and impact? Other questions relate to benefit sharing and reward mechanisms for investment in sustainable land management.

Guiding research questions are:

→ *To what extent are poor resource use efficiencies the cause of land degradation (in it different forms) and a constraint to improving land management? And to what extent are problems related to for example post-harvest losses, market access and market prices, and other economic factors like access to land and labour resources determinants of low income positions and food security; and do these provide relevant entry points for addressing food security and land degradation issues?*
→ *How do we describe rural poverty and how is this linked to land degradation?*

→ *What economic measures can be taken to improve the production and profitability of the agricultural smallholder enterprise? And what incentives can be given to farmers to improvise their soil and land management practices?*
→ *Do innovation platforms provide an effective mechanism to bring various stakeholders together and for the benefit of the farmers and to improve market chains?*
→ *Do innovation platform provide a suitable mechanism to involve farmers effectively in experimentation and in linking research to development?*
→ *What are the principal intervention strategies and options and who will benefits from these interventions?*

Output 3. Socio-economic and cultural constraints – SLM options	
Output Target 2009	Methods, protocols and indicators developed to characterize socio-cultural and economic environment and for valuation of soil ecosystem services.
	Socio-economic constraints to soil health management assessed in some agricultural productions landscapes and forest margins of the BGBD project; diagnostic carried out.
	Methods developed for socio-cultural and economic (participatory) evaluation of ecosystem goods and services developed and implemented in BGBD project sites.

COMPLETED WORK

Determinants of the decision to adopt Integrated Soil Fertility Management practices by smallholder farmers in the Central highlands of Kenya *(2009)*

Experimental Agriculture 45: 61-75

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Abstract: Declining soil fertility is a major cause of low per capita food production on smallholder farms of sub-Saharan Africa. This study attempted to provide an empirical explanation of the factors associated with farmers' decisions to adopt or not to adopt newly introduced integrated soil fertility management (ISFM) technologies consisting of combinations of organics and mineral fertilizer in Meru South district of the central highlands of Kenya. Out of 106 households interviewed, 46% were 'adopters' while 54% were 'non-adopters'. A logistic regression model showed that the factors that significantly influenced adoption positively were farm management, ability to hire labour and months in a year households bought food for their families, while age of household head and number of mature cattle negatively influenced adoption. The implication of these results is that the adoption of ISFM practices could be enhanced through targeting of younger families where both spouses work on the farm full-time and food insecure households. It is also important to target farmers that lack access to other sources of soil fertility improvement. Examples include farmers that do not own cattle or those owning few and who, therefore, have limited access to animal manure.

Constraints and new opportunities for achieving a green revolution in sub-Saharan Africa through Integrated Soil Fertility Management.

Bationo A[1]
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Abstract: African soils have an inherently poor fertility because they are very old and lack volcanic rejuvenation. In appropriate land use, poor management and lack of input have led to a decline in productivity, soil erosion, salinization and loss of vegetation. Africa is burdened with a US$ 9.3 billion annual cost of desertification. An estimate of US$ 42 billion in income and 6 billion ha of productive land are lost every year due to land degradation and declining agricultural productivity. Africa soil mining balances are often negative indicating that farmers mine their soils about $ 4 billion per year is lost due to nutrient mining. Soil moisture is perhaps the overriding constraints to food production in much of Africa and only 14% of Africa is relatively free of moisture stress. The extent of sufficient importance that steps such as recapitalization of soil fertility, Increased use of inorganic fertilizer, and more efficient recycling of biomass within the farming system are being taken. As a result of the above problem, scientists have concluded that soil-fertility depletion in smallholder farms is the fundamental biophysical root cause of declining per capita food production in Africa, and soil fertility replenishment should be considered as an investment in natural resource capital.

On-Farm Assessment of Legume Fallows and Other Soil Fertility Management Options Used by Smallholder Farmers in Southern Malawi

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Abstract: This study evaluated the performance of tree legumes and other soil fertility management innovations used by farmers. The objectives of the study were to: examine the extent that farm attributes, typology of farmers and field management practices have affected the adaptation and use of agroforestry technologies for soil fertility management and compare the agronomic performance and farmer assessment of agroforestry and other soil fertility management options, across a wide range of farmer types and field conditions, with a view to establishing the contribution of management variables to variations in yield estimation. Maize yield and farmer rating were assessed in Type II (researcher-designed, farmer-managed), Type III (farmer-designed and managed) trials and extension farmers. Results from 152 farmers show that agroforestry increased the yield of maize by 54-76% compared to unfertilized sole maize used as the control. When amended with fertilizer, the yield increase over the control was 73-76% across tree species. This indicates that farmers who had combined agroforestry with inorganic fertilizer experienced increase in maize yield attributable to the synergy between organic and inorganic fertilizer. In gliricidia-maize intercropping, higher maize yield was obtained by farmers who pruned twice. Combination of two prunings and fertilizer use gave the highest yield increase (148%) over the control and the third pruning was superfluous when fertilizer was applied. Without fertilizer, maize yield in agroforestry plots intercropped with pigeon pea was higher than those plots without pigeon pea. Planting date, fertilizer application, use of agroforestry and maize variety explained about 44% of the variation in maize yield on farmers' fields.

Crop storage efficiency and market competitiveness: Case of groundnut and cowpea in Ghana.

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Abstract: Using groundnut (*Arachis hypogea*) and cowpea (*Vigna unguiculata*), this study empirically demonstrated the correlation between crop storage and economic competitiveness of producers, captured from the degree of market integration and producer shares of the prices paid by consumers, among others. Secondary data covering 1963–1997 were used and complemented with primary data. Results from analysis of market integration showed delayed information flow among groundnut and cowpea markets, especially the latter. This suggests the absence of perfect competition and negatively affects participation of smallholder farmers in profitable marketing of groundnut and cowpea, especially during the lean season. The Harris' inverse margins from estimated equations indicated that cowpea traders, more than groundnut traders, colluded in pricing, implicating price determination outside the market forces. The attack by weevils [*Callosobruchus maculatus* (Fabricius)] and bruchids limits farmers' success in storing cowpea, creating monopoly for traders with better storage facilities coupled with chemical treatments to reduce such attacks. Price spread estimations showed that groundnut unlike cowpea farmers enjoyed a larger share of consumers' payments. The study concludes with recommendations on the need to intensify efforts in effective storage of agricultural commodities at the farm-level, as a way of improving the welfare of farm families without necessarily expanding the land area under cultivation

Promoting a Versatile but yet Minor Crop: Soybean in the Farming Systems of Kenya

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Abstract: Crop promotion is critical for market creation and rural growth in Africa. How to achieve this for crops, other than major staples (e.g., maize) and traditional export crops (e.g., tea), remains a problem since most African countries tend to focus policy attention to major staples and traditional export crops. Using a three-tier-approach, developed based on successful soybean promotion strategies in Nigeria and Zimbabwe, this study assesses the effect of market development at household-level, community level, and linking farmers' groups to industrial processors on sustainable soybean promotion in Kenya. Results show an increase in farmers' confidence to produce, process, and consume more soybeans than before. Trained farmers' groups are also developing new soybean products for cash income, a process that has proved to be very profitable. Net returns have been increased from four to 14 times for some products. Selected farmers' groups are supplying large-scale processors with soybean grains, substituting some imports.

Potential of *Warrantage* agricultural marketing system in improving rural livelihoods in Africa: Millet (*Eleusine coracana* L.) in *Madana* community, Nigeria.

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Introduction and justification

Low agricultural commodity prices are the key causes of poverty in many sub-Saharan African (SSA) countries. Efforts to improve rural livelihoods must improve agricultural produce marketing. This study was carried out to ascertain how *Warrantage* (micro-credit scheme) could be used to improve millet (*Eleusine coracana* L.) prices, marketing, returns to investment and overall livelihoods among rural farmers.

Materials and Methods

The study was carried out in *Madana* community, Jigawa State of Nigeria. The design was an action research approach, based on supervised enterprise project framework developed by the University of Cape Coast, Ghana. Data were collected using questionnaires, interviews, focus group discussions, and in-depth interviews. Data analysis was carried out using qualitative and quantitative analytical methods.

Preliminary Results

Results demonstrated how farmers could take advantage of the price differences of 50–78% between selling immediately after harvest and waiting for a few months, with the benefit–cost ratio for waiting of 1.4 to 8.7. The increase in total value of the stored millet ranges from ~9 to ~58%.

Preliminary Conclusions

The study concluded with recommendations on how the warrantage system could be expanded, institutionalized and used to increase farmers' access to modern farm inputs so as to increase their farm productivity and improved their livelihoods.

Innovative agricultural market creation in Africa: Three-tier model for soybean development and promotion in Kenya.

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Introduction

Agricultural market creation is critical for rural growth in Africa. How to achieve this based on crops other than major staples (e.g., maize) and traditional export crops (e.g., tea, coffee, cotton) remains a problem since most African countries do not give them policy attention. This study uses a three-tier-model, developed based on successful strategies in Nigeria and Zimbabwe, to develop multi-level soybean market creation in Kenya.

Materials and Methods

Data were from secondary sources, formal and informal interviews, farm-level data, and participant observations. Analysis was carried out using Microsoft Excel and SPSS.

Preliminary Results

Result shows increase in farmers' confidence to produce, process, consume, and sell more soybeans than previously. Trained farmers' groups are developing new soybean products for cash, poverty reduction and improvements in livelihoods. Net returns have been increased from four to 14 times from processed products. Selected farmers' groups have begun to supply large-scale processors with soybean grains, substituting imports. The overall project's impact on number of participating farmer groups and the actual land area devoted to soybean cultivation ranges from a factor of 2.3 to a factor of 77.4 between the long rainy season of 2005/2006 and the short rainy season of 2009. Farmers have given testimonies on live improvements.

Preliminary Conclusions

This study has demonstrated that through appropriate models, it is possible to usher in agricultural market and creation for the much desired rural growth in Africa based on the so-called non-traditional export crops and the policy-choice crops such as maize.

Environmental and Socio-economical comparison of benchmark areas of the CSM-BGBD project

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Introduction

The CSM-BGBD project is implemented in agro-ecological regions of global significance. This study aims to contrast the sites where the CSM-BGBD project operates in terms of ecological and environmental characteristics as well as in terms of socio-economic characteristics, including land use and agronomic characteristics. It will as such provide the context for the interpretation of difference we find in terms of BGBD as well as the context in which approaches and options for conservation of BGBD needs to be evaluated. I will help in determining the relevance of the findings of the project in assessing whether we find common trends in the loss of BGBD across agro-ecologies and social and economic environments.

Materials and Methods

It will require an analytical framework that is currently under discussion.
The analytical framework identifies the various indicators to be used to describe the bio-physical and socio-economic environment as well as land use and common agronomic practices. The biophysical attributes include the slope and relief intensity that are relevant attributes in assessing a range of characteristics like soil erosion, land suitability for cultivations etc. Rainfall and temperature will be used to describe climatic conditions and pH and soil organic carbon will be used as indicator of soil degradation. Socio-economic attributes include the size of the farm holdings, poverty levels and the farming systems.

Lastly the agronomic attribute will include the crops grown, the fertilizer rates and general agronomic management.

This work is considered to be part of the synthesis reporting. Data and information for this study will be obtained from the papers and reports issued by the CPC on the inventory of BGBD and characterization of each of the benchmark areas, and additional data sources.

Expected results

Results will be presented in graphs (scatter plots, bar charts etc.) that will allow for easy assessment of the differences between benchmark areas in terms of the biophysical environment and socio-economic environment. We will also combine bio-physical and soi-economic characteristic in order to see whether there are logical grouping of the benchmark areas in both these terms. We know that the benchmark areas are often located in marginal areas. We see marked differences in terms of whether rural communities depend on agriculture for their livelihoods and in the importance of conservation measures and environmental concerns.

Output 3. Socio-economic and cultural constraints – SLM options
Output Target 2010: 30% of partner farmers in pilot sites use SLM options that arrested resource degradation and increased productivity in comparison with non-treated farms.

We will look at the impact of the various activities employed especially in Southern Africa (Mozambique, Malawi and Zimbabwe) in relation to investigating and promoting Conservation Agriculture in terms of adoption of CA by farmers. There is one PhD student who will explicitly look at the adoption of CA in Mozambique and Zimbabwe and the conditions that favour this.

Output 3. Socio-economic and cultural constraints – SLM options	
Output Targets 2011	Scale-up research on soil fertility gradient to farm and landscape levels by conducting one or two carefully designed, integrated studies in collaboration with other CIAT scientists.
	Landscape dynamics assessed, social and economic constraints to improved land and soil management assessed, application domains and options for improved soil and land management identified for the majority of the TSBF project sites.

NO ACTIVITY

III.4. OUTPUT 4 - DECISION SUPPORT TOOLS FOR SUSTAINABLE LAND MANAGEMENT RECOMMENDATIONS AND NEGOTIATION SUPPORT

Outputs (Intended users)	Outcome (Impact)
Description: Decision support tools for improved targeting of recommendation for sustainable land management and negotiation support; Institutional environment and support services required for sustainable land management identified and policy recommendations. Intended users: Researchers from NARS, NGOs, Extensions services, policy makers, donor community.	Outcome & Impacts: Principles of sustainable land management integrated in local and country policies and programs and investment plans; Strategy documents inform Donor community on possible investment options and ultimately reversed land degradation contributes to global SLM goals.

Targeting of management interventions and policy recommendations

Outputs 1, 2 and 3 will provide input for the targeting of interventions. The targeting will build on the diagnoses to determine priorities for sustainable land management. The requirements for the successful implementation of recommended management interventions are matched with the locally prevailing conditions to identify a number of alternative solutions to land degradation. This process of matching results in some kind of suitability rating (aptitude) of proposed land uses and management regimes given the local conditions and circumstances (it will provide best bet solutions). Subsequently trade-offs are analyzed for the various spatial arrangements proposed for the landscape. In second instance, for each of the proposed land use and production systems a more detailed analyses of the requirements, prediction of the outputs and analyses of risks is performed.
This output will conduct cases studies within each of the major agro-ecological zones (or impact zones) that will result in recommendations for targeted intervention to improve sustainable land management. Policy interventions are required to put the necessary support functions in place to establish and enabling environment. Insights in the constraints for the adoption of SLM practices by the various stakeholder groups will inform the formulation of policy recommendations.

Guiding research questions:

→ *What are the problem domains, how are they described and identified using a participatory approach?*
→ *What are the principle management options that can be considered and what are the particular requirements for those options (what is their application domain)?*
→ *What is the target audience for the intervention and what possible intervention strategies can be employed (what are the intervention domains)?*
→ *What tools do we have available for predicting the outcome of interventions and how do we analyze the trade-offs for the various impact pathways.*

→ *What are the most efficient ways for knowledge sharing with the various stakeholder groups?*

Output 4. Decision support	
Output Targets 2009	Farmer to farmer knowledge sharing and extension through organized field trips and participatory M&E activities conducted in TSBF SLM project sites.
	Trade-off analyses conducted and policy recommendation issued for the BGBD benchmark areas.

COMPLETED WORK

Spatially optimising the distribution of agricultural input stockists in Malawi

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Abstract: Evidence indicates that much of the rural population in developing countries cannot reach stockists of farm inputs because of poor geographical accessibility (Morris et al, 2007; 23 Edmonds, 1998). Most farm input supply companies remain concentrated in urban areas or rural zones with large concentrations of commercial farmers (Kormawa et al, 2003). Therefore, millions of poor smallholder farmers in rural areas do not have access to affordable agricultural inputs, such as, improved seeds, chemical fertilizers, and other agro-chemicals needed to help them raise their farm productivity. The poor development and weak performance of rural agricultural input markets explain to a large extent the current low productivity of smallholder farmers (Rockefeller Foundation, 2002).
Farmers often travel great distances to access basic farm supplies and in most cases find the supplies unaffordable. This has made it difficult for small-scale farmers to increase their yield or incomes, leaving them stuck in poverty. Studies by Kherallah *et al.* (2000) and Kydd *et al.* (2004) revealed that, although there have been pockets of increased input use (e.g., some export crop sectors), the vast majority of Africa's smallholder farmers rarely use modern inputs. This is particularly so for farmers located in remote areas, where poor transport infrastructure increases input prices (Jacoby, 2000; Kelly *et al.*, 2003; Kamara, 2004; Morris et al, 2007) and reduces output prices. A study to explore ways of expanding input use in Africa (Kelly *et al.*, 2003) concludes that governments in sub-Saharan Africa (SSA) can play a very important role in promoting the expansion of input use beyond the initial adopters. The study also argues that SSA governments (with donor support) need to invest in the basic public goods that will stimulate farmers to intensify agricultural production, and the commercial sector to supply improved inputs. Among the important public goods to be invested in are rural infrastructure (roads, markets, electrification), basic education (particularly in rural areas), agricultural research and extension, and market information systems. Until there is serious commitment to providing these basic public goods, large-scale government input subsidies, credit, or distribution programs are unlikely to have any lasting impact on agricultural intensification, rural incomes, national food security, or poverty reduction.

Output 4. Decision support tools	
Output Targets 2010	Profitable land use innovations scaled out beyond pilot learning sites through strategic alliances and partnerships, and application of alternative dissemination approaches.
	Decision support framework for soil and land use management recommendation developed and validated in pilot learning sites in 5 countries in SSA.
	Strategies for institutionalization of participatory NRM approaches and methodologies established.

WORK IN PROGRESS

Biological nitrogen fixation by rhizobia and mineral fertilizer savings: implications for green revolution in Africa

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[1]CIAT-TSBF, Kenya; [2]University of Ghana, Legon

Introduction and justification

Although it is common knowledge that soil microorganisms form an important component of below ground biodiversity, providing important ecosystem services that may sustain and enhance agricultural production, few policies have been formulated that deliberately seek to benefit from the services provided. Applying the knowledge gained from on-station and on-farm trials in Africa, complemented with necessary assumptions on FAO-sourced soybean data, this study contributes to awareness on the importance of these microorganisms by estimating the financial value of N-fixation (which helps to cut down the N-fertilizer needs of soybean and the subsequent maize) of legume nodulating bacteria (LNB) associated with promiscuous soybean varieties.

Materials and Methods

This study was carried out using FAO data from 19 African countries. Evaluation of the financial value was based on the method of cost savings in terms of mineral N fertilizer that would have been required to attain the same level of N fixed biologically.

Preliminary Results

Results show that the financial value of the N-fixing attribute of soybean in Africa, especially the promiscuous varieties, annually amounts to ~US$ 200 million across the 19 countries. With the fertilizer price of~US$795 t^{-1} (June 2008), this would amount to US$ 375 million. Given these huge benefits from soybean BNF, and the potential to further expand it, this paper outlined four strategies (expansion of the area under soybean cultivation, soybean yield increase through an increase in the N-fixed per hectare, use of P fertilizer to increase the yield of soybean, and inoculation of promiscuous soybean varieties with Bradyrhizobium) for increasing the appropriation of the benefits from BNF for improved welfare of farm families in Africa.

Preliminary Conclusions

Given the current prevailing circumstances in Africa, expansion of the area under soybean cultivation could be argued to be the most promising strategy. However, the sustainability of this strategy will depend on the extent of market and infrastructural development. Next is the use of P fertilizer to increase the yield of soybean. Use of P fertilizer can easily lead to the doubling of soybean yield as has been demonstrated both on-station and on-farm under farmer management. The remaining two strategies (soybean yield increase through an increase in the N-fixed per hectare and inoculation of promiscuous soybean varieties with Bradyrhizobium), require investments in the areas of plant breeding, market stimulation, and infrastructural development to mention but a few. In other words, a strong policy and political support is essential.

Innovative agricultural market creation in Africa: Three-tier model for soybean development and promotion in Kenya

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Introduction

Agricultural market creation is critical for rural growth in Africa. How to achieve this based on crops other than major staples (e.g., maize) and traditional export crops (e.g., tea, coffee, cotton) remains a problem since most African countries do not give them policy attention. This study uses a three-tier-model, developed based on successful strategies in Nigeria and Zimbabwe, to develop multi-level soybean market creation in Kenya.

Materials and Methods

Data were from secondary sources, formal and informal interviews, farm-level data, and participant observations. Analysis was carried out using Microsoft Excel and SPSS.

Preliminary Results

Result shows increase in farmers' confidence to produce, process, consume, and sell more soybeans than previously. Trained farmers' groups are developing new soybean products for cash, poverty reduction and improvements in livelihoods. Net returns have been increased from four to 14 times from processed products. Selected farmers' groups have begun to supply large-scale processors with soybean grains, substituting imports. The overall project's impact on number of participating farmer groups and the actual land area devoted to soybean cultivation ranges from a factor of 2.3 to a factor of 77.4 between the long rainy season of 2005/2006 and the short rainy season of 2009. Farmers have given testimonies on live improvements.

Preliminary Conclusions

This study has demonstrated that through appropriate models, it is possible to usher in agricultural market and creation for the much desired rural growth in Africa based on the so-called non-traditional export crops and the policy-choice crops such as maize.

Output 4. Decision support tools
Output Targets 2011: Social science aspects are included in the decision-making process and tools to better understand actionable management strategies for landscape management, their knowledge requirements, and economics.

NO ACTIVITY

III.5. OUTPUT 5 - STAKEHOLDER CAPACITY FOR SUSTAINANBLE LAND MAMANGEMENT ENHANCED

Outputs (Intended users)	Outcome (Impact)
Description: Stakeholder capacity to advance the development and adaptation of recommendations for improved land management enhanced; effective dissemination of results and advocacy for sustainable land management. Intended users: CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, 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.

Capacity building

Capacity building will be cross cutting through each of the outputs listed. Capacity building will done through graduate and post-graduate training, on the job-training of NARS and University staff that directly participate in the implementation of the projects, through short term training courses and stakeholder meetings and workshops. The graduate and post graduated training will be mostly associated with output 1, whereas on the job-training will be associated mainly with output 2 and output 3 to some extent. The training workshops and stakeholder meetings/workshop will be the main modus of capacity building for outputs 3 and 4. Most of the graduate and post-graduate training will be done through direct supervision of CIAT-TSBF staff though most of the training will be provide through the universities that participate in the CIAT-TSBF SLM research projects. Otherwise Afnet will play an important role in the provision of informal training. For stakeholder workshop and meetings we will increasingly try to involve and interest non-governmental organizations.

Output 5. Stakeholder capacity	
Output Targets 2009	Web content of the BGBD website enhanced to contain data and information on taxonomy and species identification, methods for inventory and characterization of BGBD, Synthesis reports on inventory, indicators of BGBD loss and soil biological quality indicators and management option and techniques for managing BGBD.
	Documentation on integrated approach to the management of agricultural production landscapes with respect to soil health and conservation of the soil resource base.

Strengthening the capacity of agro-input dealers in Integrated Soil Fertility Management Technologies in Eastern Tanzania: Results, challenges and opportunities

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Introduction and justification

Integrated Soil Fertility Management (ISFM) has been widely seen as a sustainable way of increasing agricultural productivity in sub-Saharan Africa (SSA). Due to the weakness in the functioning of formal extension services in most African countries, the study evaluates the results, challenges and opportunities in engaging agro-input dealers to complement formal extension systems in the extension of ISFM technologies.

Materials and Methods

The study was carried out in *Kilosa* and *Mvomero* districts of Eastern Tanzania. Forty CNFA certified agro-input dealers (18 females, 22 males) were involved and trained on different components of ISFM (e.g. planting of improved maize varieties, use of mineral fertilizers, use of organic fertilizers, application of herbicides, control of crop storage pests, etc).

Preliminary Results

Most of the agro-input-dealers had very limited knowledge on soils, mineral fertilizers, and correct methods of mineral fertilizer application. Results from end of course evaluation revealed that most (90%) agro-input dealers appreciated the knowledge gained and would extend the same to farmers, even through the use of demonstration plots. The agro-input dealers appreciated their interaction with research scientists and would wish scientists to visit and advise them more frequently. An initial challenge was to arouse and hold the interest of the agro-input dealers, given that they were not used to being involved in agricultural extension services. However, this was short-lived when agro-input dealers realized that getting involved in training on ISFM was a potential way of sustainably growing their business for increased turnover and better business returns. This even created a great opportunity to take advantage of the increasing network of agro-input dealers in Tanzania to expand the work and bring about the much desired increased agricultural productivity in the country and probably elsewhere in SSA.

Preliminary Conclusions

The study concludes noting that capacity-building of agro-input dealers on ISFM has great potential in scaling out ISFM technologies to reach millions of small-scale farmers in SSA.

Training agro-input dealers on the use of soil test kits: Case of *Kilosa* and *Mvomero* districts in Eastern Tanzania.

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[1]CIAT-TSBF, Kenya [2]Agricultural Research Institute Ilonga, Tanzania; [3]CNFA/TAGMARK, Tanzania

Introduction and justification

Soil analytical data from laboratories is often the basis for recommending the quantity and type of fertilizers and soil amendments to apply for improved crop productivity. However, this is costly and takes time before data become available. Soil test kits are cheap and easy to handle and does not require very highly qualified personnel. Selected agro-input dealers were trained to use soil kits for quick testing of soils. This study examines the outcome.

Materials and Methods

The study was carried out in *Kilosa* and *Mvomero* districts in Eastern Tanzania. The agro-input dealers were trained on how to interpret the nutrient indicator colours obtained following the use of the soil test kits in assessing the nutrient status of the target soils. Forty CNFA certified agro-input dealers (18 females, 22 males) were trained.

Preliminary Results

At the end of the training, the agro-input dealers could accurately determine: (i) soil pH, (ii) soil nitrogen, (iii) soil phosphate, (iv) soil potash, and (v) soil organic matter. Based on their new ability to interpret the colours from the soil test kit, they are now able to at least inform their customers (farmers) about the nutrient status of their fields (e.g., in terms of whether the P-level is adequate, medium or completely inadequate).

Preliminary Conclusions

The idea and approach of training agro-input dealers on the use of soil test kits has been shown to have prospects of increasing the use of mineral fertilizers by smallholder farmers and also the use efficiency of such important and often scarce and costly farm inputs. The challenge is to ensure steady availability of the chemicals and the provision of such services at costs affordable by the target small-scale farmers.

COMPLETED WORK

Institutional innovation: the potential of the warrantage system to underpin the green revolution in Africa

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Abstract: The warrantage or inventory credit system was developed to address the liquidity constraints that farmers encounter while trying to intensify their production systems. The scheme removes barriers to the adoption of soil fertility restoration technologies by ensuring that farmers have access to cash, technical advice, and inputs. Farmers use the credit to purchase external inputs, such as fertilizers and seeds, and to invest in dry season income generating activities, such as fattening of small ruminants, vegetable growing, trading, and groundnut oil extraction. In an earlier study funded by USAID, it was found that the fertilizer microdosing technology increased by 52 to 134 %. In a project funded by the Challenge Program on Water and Food (CPWF), farmers are responding positively to the implementation of warrantage in two communities in the village of Ziga and Saala in Burkina Faso. This scheme is getting increasing support from donors for its wider promotion in Sub-Saharan Africa. The constraints to the development and implementation of warrantage include lack of capital for Decentralized Financial Systems (DFS) to grant loans and for supervising bodies to provide guarantees, government interference through dumping imported commodities onto the market, lack of infrastructure at the village level, and lack of well-organized farmer associations. An analysis of the constraints to the implementation of the scheme as well as the factors underlining the promotion and use of the warrantage system are also discussed.

Output 5. Stakeholder capacity	
Output Targets 2010	Validated intensive and profitable systems are being demonstrated, promoted by partners and adopted by farmers in 10 countries.
	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.
	Stakeholder workshops in selected productions landscapes involving national and local stakeholders, presenting recommendations for improved soil and land use management.
	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.

Work on empowering farmer communities, establishment of innovation platforms for Conservation Agriculture etc. are being conducted in several projects of CIAT-TSBF. There are also project that aim to train Agro-dealers in ISFM practices so that they can better inform farmers on ISFM. See for reports on the progress of these activities the ISFM outcome line. Part of the output targets refer to the AfSIS project where stakeholder workshops and training will take place as well. For most of these activities we do not expect the targets to be realized in 2010, but probably in the subsequent two years.

Output 5. Stakeholder capacity	
Output Targets 2011	Improve linkages with the private sector to improve access to fertilizer and develop recommendations for its use by farmers and other stakeholders involved.
	Demonstration and documentation of successful cases prove approach and methodology used and will generate additional funds for out scaling of the activities (donor buy-in) NGO adopt methodology and will lead to improved adoption and policy formulation.
	Degree training (BSc, MSc and PhD) on relevant topics.
	Short term training courses (methods for inventory of BGBD, Decision support tools for recommendations on soil and land use management, Economic valuation and PES, etc).

WORK IN PROGRESS

Agro-input dealers taking a lead in demonstrating Integrated Soil Fertility Management Technologies in Eastern Tanzania: Challenges, opportunities and prospects

J. N.Chianu[1], C.Z. Mkangwa[2], J. Miingi-Kaiza[3], B.Vanlauwe[1], and S. Koala[1]
[1]*CIAT-TSBF, Kenya*

Introduction

Demonstration is often used to show or explain how something works or is done. Following the completion of training on fertilizer use and management as components of Integrated Soil Fertility Management (ISFM), 40 CNFA certified agro-input dealers (18 females, 22 males) were required to show their understanding of what they had learnt by leading the establishment of one ISFM technology demonstration plot. The aims were to make agro-input dealers practice what they learnt, expose them to the effects of various inputs (fertilizers and seed) and their interactions as affected by differences in soils and soil fertility status.

Materials and Methods

The study was carried out in Kilosa and Mvomero districts of Eastern Tanzania. Maize (*Zea mays*) was the test crop. Agro-input dealer participatory approach was used in deciding the treatments: the control, 40 and 80 kg N ha^{-1} applied with 0 or 40 kg P ha^{-1}, and 80 kg N ha^{-1} as NPK (20:10:10). Nitrogen and P sources were urea and *Minjingu* phosphate rock (MPR). Soils sampled from all demonstration sites were analysed using standard analytical procedures.

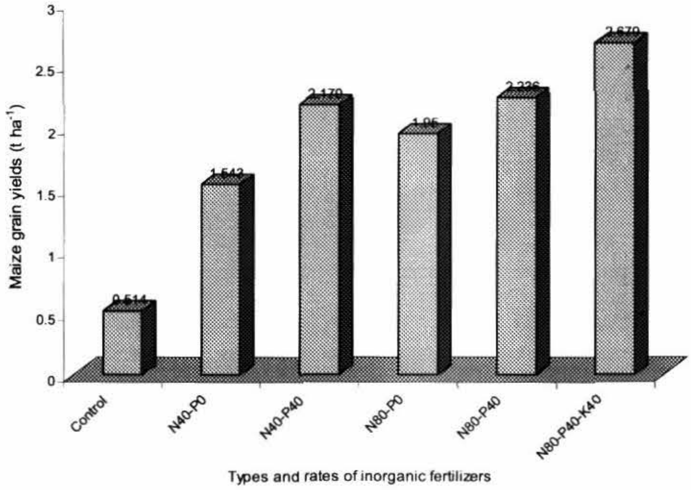

Figure 12: Influence of inorganic fertilizers on maize yields on fields of some agro-input dealers of Kilosa and Mvomero districts, Tanzania

Preliminary Results

Results showed that most sites were deficient in both N and P, with soil pH ranging from 5.6 to 8.2. Maize (var. TMV-1) responded to both fertilizers, with most sites giving higher yields (2.2–2.7 t ha-1) with MPR+urea and NPK treatments. Maize responses to the different fertilizer materials and rates are summarized in **(Figure 12)**. Despite that maize showed a good response to MPR, agro-input dealers noted that MPR was not known to most farmers.

Preliminary Conclusions

The successful agro-input dealer led demonstration of ISFM technologies was a clear indication of the prospect in involving trained agro-input dealers in related agricultural services extension to reach millions of farmers in Africa and create an overall increase in agricultural productivity and production. One clear and advantageous feature of agro-input dealers' involvement in field demonstrations was that they easily and frequently interact with small-scale farmers. Besides, in explaining the outcome of various demonstrations, agro-input dealers are able to apply local examples that are easily followed and understood by farmers.

IV. LIST OF STUDENTS

List of students in the CSM BGBD project in 2009

Country	Names	Degree	Year	Institution	Status	Title
Brazil	Alves e Silva Glaucia	Doctorate	2009	UF de Lavras	In progress	Diversity of arbuscular mycorrhizal fungi isolated from Western Amazon soils
Brazil	Alves e Silva Glaucia	Doctorate	2009	UF de Lavras	in progress	Functional diversity of arbuscular mycorrhizal fungi from western Amazon region. Defense foreseen to February 2009.
Brazil	Alves Mauricio V.	Doctorate	2009	UF de Lavras	in progress	Soil structure as related to fauna activity in western Amazon region. Defense foreseen to December 2009.
Brazil	Silva Krisle da	Doctorate	2009	UF de Lavras	in progress	Functional and genetic diversities of Burkholderia spp. from western Amazon region. Defense foreseen to August 2009.
Brazil	Korasaki Vanesca	Doctorate	2009	UF de Lavras	in progress	Ant Community Structure along a gradient of land use intensity in Upper Solimoes River, Brazil
Brazil	Soares Bruno L.	Masters	2009	UF de Lavras	in progress	Simbiotic efficiency of nitrogen-fixing bacterial strains in cowpea and their acidity and aluminum tolerances "in vitro". Defense foreseen to February 2009.
Brazil	Martins Paula C. C.	Masters	2009	UF de Lavras	in progress	Evaluation of soil structure sustainability by the bearing capacity model in Brazlian western amazon. Defense foreseen to February 2009.
Brazil	Oliveira Silvia	Masters	2009	UF de Lavras	in progress	Functional and genetic diversities of nitrogen fixing bacterial strains symbionts of cowpea and common beans: Defense foreseen to February 2009.
Brazil	Navarrete Acacio A.	Masters	2009	CENA	in progress	Archaeal community diversity and structure in soils of the western Brazlian Amazon Defense

						foreseen to August 2009.
Brazil	Braga Rodrigo	Masters	2009	UF de Lavras	in progress	Effects of land use changes over the ecosystem services provided by Scarabaeinae dung beetles in Brazilian Amazon. Defense foreseen to February 2009
Brazil	Cassetari Alice S.	Monografy	2008	UF de Lavras	Concluded	Biological nitrogen fixation and phosphate solubilization by Burkholderia spp. isolated from Amazonian soils.
Brazil	Silva, Thami	Monografy	2009	UF de Lavras	In progress	Epigeic Ant diversity in Amazon forest soils.
India	Bhadauria Tunira	Doctorate	2009	JNU	field work	Using earthworms for sustainable agroecosystem development and rehabilitation of degraded lands
India	Dangwal Divya	Doctorate	2009	GBPHIED/ HNB Garhwal University	In Progress	Assessment of productivity, nutrient uptake and nitrogenase activity in three selected mountain legume crops under mix and monocropping
India	Chamoli K.P.	Post-doc	2009	GBPHIED	In Progress	Documentation of indigenous knowledge related sol fertility maintenance in Central Himalaya agroecosystem
India	Rawat L.S.	Post-doc	2009	GBPHIED	In Progress	Impact of Bio-compost and Vermicompost on yield of Rabi & Kharif season crops.
India	Kumar Lalit	Doctorate	2009	GBPHIED/ HNB Garhwal University	In Progress	Productivity of agricultural crops and an alpine pasture in Garhwal Himalaya in relation to global environmental change.
India	Pant Santosh	Masters	2009	GBPHIED/ HNB Garhwal University	In Progress	Studies on soil macrofauna of buffer zone agroecosystem of NDBR.
India	Misra Shalini	Doctorate	2009	GBPHIED/ HNB Garhwal University	In Progress	Studies on forest disturbances in different management categories of Kedarnath Wildlife Sanctuary, Uttaranchal
India	Gupta Subho Das	Doctorate	2009	GBPHIED	In Progress	Soil fauna activity in pastures
India	Kundu Sumanta	Doctorate	2009	GBPHIED	In Progress	Soil fauna activity in a village landscape. Studies on village ecosystem function in Rawain valley of Central Himalaya: An ecological -

						economics approach.
India	Negi V.S.	Doctorate	2009	GBPHIED/ HNB Garhwal University	In Progress	Survey and identification of soil macrofauna of NDBR
India	Singh Yudvir	Post-doc	2009	GBPHIED	In Progress	Survey and identification of soil macrofauna of NDBR
India	Sringeswara A.N.	Doctorate	2009	Kuvenmpu University	Submitted	Analysis of the vegetation in the Kudremukh National Park region of the western ghats, India.
India	Pande Himanshu	Doctorate	2009	Kumaon University	In Progress	Macrofauna diversity and abundance in Nanda Devi Biosphere Reserve
India	Rane Ajay	Doctorate	2009	KFRI	In Progress	Assessment of soil quality and management practices in different land use types in the Kerala part of Nilgiri Biosphere Reserve
India	Baiju E.C.	Doctorate	2009	KFRI	In Progress	Land use and landscape dynamics in a micro - watershed of Chaliyar River in Kerala part of Nilgiri Biosphere Reserve
India	Binu N.K.	Research fellow	2009	KFRI	In Progress	Distribution and diversity of arbuscular mycorrhizal fungi in different land use systems in the Kerala part of Nilgiri Biosphere Reserve.
India	Rahman P. Mujeeb	Research fellow	2009	KFRI	In Progress	Soil faunal diversity under different landuse systems in the Kerala part of Nilgiri Biosphere Reserve
India	Bineesha S.	Research fellow	2009	KFRI	In Progress	Diversity and dynamics of nitrogen fixing bacteria under different landuse systems in the Kerala part of Nilgiri Biosphere Reserve
India	Sahu Jithnedra Kumar	Research fellow	2009	Sambalpur University	In Progress	Linkages between soil morphology and soil fauna in natural forests in Nilgiri Biosphere Reserve
India	Narhari	Research fellow	2009	Sambalpur University	In Progress	Soil chemical characteristics in relation to soil macrofauna
India	Patra Debashish	Research fellow	2009	Sambalpur University	In Progress	Soil ecological studies
India	P. Nirmala	Project fellow	2009	University of Agricultural Sciences, (UAS)	In Progress	Agricultural entomology

				Bangalore		
India	M.S. Kitturmath	Project fellow	2009	UAS Bangalore	In Progress	Agricultural entomology
India	M. Raghavendra Kumar	Ph.D. UAS	2009	UAS Bangalore	In Progress	Agricultural microbiology
India	K.S. Usha	Project fellow	2009	UAS Bangalore	In Progress	Agricultural microbiology
India	R. Sabu	Project Fellow	2009	KFRI, Nilambur	In Progress	Soil science
India	V. M. Nishad	Doctorate	2009	KFRI, Nilambur	In Progress	Microbiology
India	Rohit Kumar	Project Fellow	2009	GBPHIED, Srinagar	In Progress	Soil Zoology
India	Pradeep Kumar	Project fellow	2009	GBPHIED, Srinagar	In Progress	Soil zoology
India	Joylata Laishram	M.Phil, JNU	2009	JNU, NewDelhi	In Progress	Resource integration
India	Madhuri Dabral	Doctorate	2009	G.K. University, Hardwar & GBPHIED,	Ph.D. Thesis submitted	Land use and Earthworms
Mexico	Hernández Lizbeth	Licenciatura	2009	University Veracruzana	in progress	Efecto de diferentes usos del suelo sobre las comunidades de hormigas (Hymenoptera: Formicidea) en la Sierra de Santa Marta, Los Tuxtlas, Ver.
Mexico	Miranda Carlos A	Licenciatura	2009	University Veracruzana	in progress	Manejo de palma camedor en dos ejidos de la región de Los Tuxtlas. Tesis de Licenciatura Facultad de Biología. Universidad Veracruzana, Xalapa, Ver.
Mexico	Mondragón Gómez Alberto	Licenciatura	2009	UNAM	in progress	Evaluación de la actividad enzimática en suelos bajo diferente uso en los Tuxtlas Veracruz
Mexico	Lloret Lourdes	Doctorate	2009	UNAM	in progress	Diversidad de rizobios en Los Tuxtlas y en el Cañon del Sumidero en Chiapas
Mexico	Ormeño Orrillo	Doctorate	2009	UNAM	in progress	Diversidad de Bradyrhizobium de los Tuxtlas y

	Ernesto					de Phaseolus lunatus.
Kenya	Amek Tom	Masters	2009	University of Nairobi	Completed	Ex-ante analysis of Technology adoption
Kenya	Achieng Celline Oduor	Masters	2009	Kenyatta University	*Completed*	Policy framework for utilization and conservation of below-ground biodiversity *in* Kenya
Kenya	Adama Moses	Masters	2009	University of Nairobi	writing	The Nexus Between Social And Economic Institutions, Intensive Farming And The Management Of Belowground Biodiversity: A Study Of Wundanyi Division, Taita-Taveta District.
Kenya	Mugambi Benson Rimbera	Masters	2009	University of Nairobi	writing	Impact of Land use changes on Nematode diversity and abundance in Taita and Embu
Kenya	Chirchir Joseph K.	Masters	2009	University of Nairobi	field work	Crop production practices and biodiversity conservation in Taita Taveta district
Kenya	Wanjiru Mwangi Margaret	Masters	2009	Kenyatta University	Data analyses	Effect of T*richoderma harzianum* and arbuscular mycorrhizal fungi on growth and diseases management in tea cuttings, tomato seedlings, and napier grass
Kenya	Maina Peter K.	Masters	2009	Kenyatta University	Data analyses	The impact of land use on Distribution and Diversity of *Fusarium spp*. in Ngangao Forest and its adjacent farmlands
Kenya	Siameto Elizabeth	Masters	2009	University of Nairobi	Thesis writing	Molecular characterization and determination of biocontrol activity of *Trichoderma harzianum* (Green mould) isolates from Embu District, Kenya
Kenya	Mukundi David	Masters	2009	University of Nairobi	Thesis writing	Distribution and diversity of *Pythium* spp in Irangi and Ngangao forest, Embu, Kenya
Kenya	Muya Edward	Doctorate	2009	University of Nairobi	Proposal writing	Management practice for improved soil structure, nutrient availability and water use efficiency of degraded acid soils.
Kenya	Kibberenge Musobi	Doctorate	2009	University of Nairobi	Field work	
Kenya	Wachira Peter M.	Doctorate	2009	University of Nairobi	Field work	Enhancement of Nematophagous fungi on agricultural systems for biological control of

						nematodes
Kenya	Tepeny Taabu T.	Doctorate	2009	University of Nairobi	Field work	Effect of land use and soil management practices on the control of the Phytopathogenic Rhizoctonia species in Taita hills
Kenya	Nyaga John	Masters	2009	JKUAT	Field work	Effect of Land Use Practices on Occurrence of Arbuscular Mycorrhizal Fungi (AMF) and Use of AMF Inoculum for Sustainable Crop Production in Taita Taveta and Embu Districts; Kenya
Kenya	Mwangi Ngare S.	Masters	2009	JKUAT	Lab. analysis	Genetic diversity of leguminous nitrogen fixing bacteria and their symbiotic potential in Taita Taveta region, Kenya
Kenya	Mwenda George	Masters	2009	JKUAT	Lab analysis	Genetic diversity and symbiotic efficiency of Rhizobia isolated from Embu, Kenya
Kenya	Wambugu Maribie C.	Masters	2009	University of Nairobi	Data analyses	Assessment of Acari diversity and densities in different land use types in Embu and Taita, Kenya
Kenya	Wephukulu Miriam	Masters	2009	University of Nairobi	Data analyses	Abundance of *Bacillus subtilis* and root –knot nematodes under different soil fertility management practices
Kenya	Otandoh Jane	Masters	2009	University of Nairobi	Field work	Efficacy trial on virulence of Trichoderma on the pathogenic fungi in Embu
Kenya	Kitivo Emily	Masters	2009	University of Nairobi	Data analyses	Investigation into the role of termite in soil structure and composition in relation to agricultural productivity.
Kenya	Sirengo Ann	Masters	2009	University of Nairobi	Data entry	Determinants of farmer use of agricultural management practices that enhance the population of beneficial soil organisms: The case of earthworm conservation in Kenya
Kenya	Muturi Jamleck	Doctorate	2009	Kenyatta University	Field work	Influence of land use practices on the diversity and density of collembola in Embu and Taita, Kenya
Kenya	Antony Aseta	Masters	2009	JKUAT	Green house	
Kenya	Kawaka Fanwel	Masters	2009	Kenyatta University	Lab.	

					analysis	
Kenya	Mwangi James	Masters	2009	Kenyatta University	Lab. analysis	
Kenya	Juma Imelda	Doctorate	2009	University of Nairobi	Lab. analysis	
Uganda	Nkwiine Charles	Doctorate	2009	Makerere University	data analyses	
Uganda	Zawedde Justine	Masters	2009	Makerere University	Submitted	
Ivory Coast	Yannick Baidai	Bachelor	2009	Universitaire de technologie	*In progress*	Role of the earthworm Dichogaster-terrae nigrae in soil compaction in agrosystems of Centre-West Côte d'Ivoire
Ivory Coast	Serge Kassi	Master	2009		In progress	Can earthworms from savanna grow and survive in soil from the forest?
Ivory Coast	Amon Bosso	Master	2009		In progress	Biological quality of soil in Centre-West Côte d'Ivoire: role of soil macro-invertebrate
Ivory Coast	Cyrille B. Amani	Master	2009		In progress	Economic value of agrosytems in Centre-West Côte d'Ivoire
Ivory Coast	Blandine Sey	Master	2009		Submitted	Impact of land-use systems on floristic diversity in Centre-West Côte d'Ivoite
Ivory Coast	Aurélie N'Dri	Master	2009		In progress	Impact of land-use systems on enzyme activities in Centre-West Côte d'Ivoire: do earthworms play a role?
Ivory Coast	Paul Assié	PhD	2009		Submitted	Pedo-morphological characterization of soils in agrosystems from Center-West Côte d'Ivoire
Ivory Coast	Julien K. N'Dri	PhD	2009		Submitted	Acari as indicators of soil ecosystem disturbance in Côte d'Ivoire
Ivory Coast	Arnault Guéi	PhD	2009		Submitted	Building a synthetic index of soil quality based on soil macroinvertebrates in Côte d'Ivoire
Ivory Coast	Gérard K. N'Goran	PhD	2009		Submitted	Soil biodiversity and agricultural productivity: the perception of farmers from Centre-West Côte d'Ivoire

V. LIST OF PARTNERS

Partners per country

Austria: University of Natural Resources and Applied Life Sciences (BOKU)
Brazil: Universidade de Brasilia (UNB),Universida Regional de Blumenau (FURB) Universidade Federal de Lavras (UFLA),Insituto Nacional de Pesquisada Amazonia (INPA),Universidade Federal do Amazonas (UFAM),Centro de Energia Nuclear na Agricultura (CENA),EMBRAPA Solos,Centro de Ensino Luterano de Manaus (CEULM/ULBRA)
Cote d'Ivoire : Houphouët-Boigny National Polytechnic Institute (INP-HB/ESA),Université d'Adobo-Adjamé (UAA),Universite de Cocody (UC),Centre National de Recherche Agricole (CNRA),Ecole Supériere d'Agronomie du Bureau National d'Etudes et des Travaux (BNETD/CCT),Ivorian Center of Economic and Social Research (CIRES),National Agency for Rural Development (ANADER)
S.O.S-Forêts (NGO), SODEFOR (State Forest Agency)
India: University of Agricultural Sciences (UAS), Kumaon University
Kerala Forest Research Institute (KFRI),Sambalpur University,Jawaharlal Nehru University (JNU),Delhi University (DU), G.B. Plant Institute of Himalayan Environment Management (GBPIHEM).
Indonesia: Universitas Lampung, Brawijaya University, Gadjah Mada University, The Southeast Asian Regional Centre for Tropical Biology (BIOTROP),Research Institute for Agricultural Biotechnology and Genetic Resources (RIABGR),Forestry and Estate Research and Development Agency (FORDA),Biotechnology Research Institute for Estate Crops (BRIEC),Centre for Soil and Agroclimate Research, Bogor Agricultural University
Kenya: Kenya Agricultural Research Institute (KARI), Kenya Forestry Research Institute (KEFRI), University of Nairobi (UoN), National Museums of Kenya (NMK), Department of Resources Survey and Remote Sensing (DRSRS), United States International University (USIU), Methodist University
Malawi: Bunda College of Agriculture, Agricultural Research Station Chitedze
Mali: Institut d'Economie Rurale (IER), Mali
Mexico: Instituto de Ecologia A.C., Instituto Fitosanidad, Colegio de Posgraduados (IFCP), Universidade Autonoma de Mexico (UNAM), Universidade Veracruzana,
Instituto Politécnico Nacional (IPN), National Institute of Forestry, Agricultural and Animal Research (INIFAP), Centro Experimental San Andres-Tuxtlas, Biosphere Reserve Los Tuxtlas, Group Vincemte Guerrero de Tlaxcala (NGO), Red A.C. (NGO)
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Mozambique: Catholic University Mozambique (UCM), Mozambique, Instituto de Investigação Agrária de Moçambique (IIAM)
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Republic of South Africa: University of Pretoria, RSA, University of KwaZulu Natal University of Free State, RSA
Tanzania: Selian Agricultural Research Institute (Tanzania), Agricultural Research Institute (ARI) Tanzania,
Uganda: Uganda Environmental Education Foundation (UEEF), Uganda
Africa 2000 Network (A2N), Uganda, Makerere University (MUK), Uganda, Appropriate Technology (AT), Uganda NARO, Uganda, National Forest Authority (NFA),National Environment Management Authority (NEA),Ministry of Agriculture (MOA)

Partners per type of institution

NARS: Bunda College of Agriculture, Malawi, Makerere University (MUK), Uganda University of Pretoria, RSA,NARO, Uganda,Catholic University Mozambique (UCM), Mozambique ,University of KwaZulu Natal, RSA, Instituto de Investigação Agrária de Moçambique (IIAM),University of Free State, RSA, Kenya Agricultural Research Institute (KARI). Kenya Forestry Research Institute (KEFRI),University of Nairobi (UON),National Museums of Kenya (NMK), Department of Resources Survey and Remote Sensing (DRSRS),United States International University (USIU, Methodist University, Instituto de Ecologia A.C., Mexico, Instituto Fitosanidad, Colegio de Posgraduados (IFCP), Mexico, Universidade Autonoma de Mexico (UNAM), Mexico.
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Université d'Adobo-Adjamé (UAA), Cote d'Ivoire, Universite de Cocody (UC), Cote d'Ivoire, Centre National de Recherche Agricole (CNRA), Cote d'Ivoire, Ecole Supériere d'Agronomie du Bureau National d'Etudes et des Travaux (BNETD/CCT), Cote d'Ivoire Ivorian Center of Economic and Social Research (CIRES), Cote d'Ivoire, National Agency for Rural Development (ANADER), Cote d'Ivoire, SODEFOR (State Forest Agency), Cote d'Ivoire, University of Agricultural Sciences (UAS), India, Kumaon University, India, Kerala Forest Research Institute (KFRI), India, Sambalpur University, India, Jawaharlal Nehru University (JNU), India, Delhi University (DU), India, G.B. Plant Institute of Himalayan Environment Management (GBPIHEM), India, Agricultural Research Institute (ARI) Tanzania, Selian Agricultural Research Institute (Tanzania), Institut d'Economie Rurale (IER), Mali ,University of Zimbabwe, Zimbabwe. United Nations System: Luis Álvarez-Wélchez, Germán Flores, Carlos Zelaya and Walter Alvarenga, Food and Agriculture Organization of the United Nations (FAO), Honduras. Octavio Menocal, Jellin Pavón, Oscar Poveda, José Luis Olivares and Roberto Paredes, Nicaraguan Institute for Agricultural Technology; Edgar Amézquita, Miguel Ayarza, Colombian Corporation for Agricultural Research (CORPOICA), Colombia.

Advanced Research Institutes: Wageningen University and Research centre, The Netherlands, Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden, University of Natural Resources and Applied Life Sciences (BOKU) ,Cornell University, USA, Institut de Recherche pour le Développement, France , Matilde Somarriba, Bismark Mendoza, Ignacio Rodríguez, Glenda Bonilla, National University of Agriculture (UNA), Nicaragua*; Zoila Ávila, Oscar W. Ferreira and Oscar Ferreira Catrileo, National School of