Output 5
Sustainable land management for social profitability developed, with special emphasis on reversing land degradation

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Rationale

Strategic and component research to date has been conducted largely at the plot or field scale, where interactions among various agricultural enterprises are seldom considered. Although TSBF-CIAT's strength remains at the plot level, the diversity of forces impinging on the plot naturally draws attention towards a hierarchical systems-based approach. The next generation of work will be at higher scales, particularly the farm and landscape scales. The rationale for working at the farm scale is the need to improve nutrient use efficiency through better allocation of the limited organic and inorganic resources among different enterprises, taking into consideration inherent soil variability within the farming system. Inadequacies in supplies of both organic and inorganic nutrients have created strong fertility gradients even within the smallest farms. Smallholder farmers typically remove harvest products and crop residues from their food producing 'outfields' and devote their scarce soil inputs to their smaller market 'infields', resulting in large differences in soil productivity over time between these two field types. Understanding how to manage the limited nutrient supplies across such fertility gradients is a key component in raising productivity in fields of staple crops.

Interest in the quality and health of soil has grown with the recognition that soil is vital not only to production of food and fiber, but also the smooth functioning of the ecosystem, and overall environmental stability. Agriculture needs economically viable and ecologically sound soil management practices that provide sufficient food and yet maintain environmental stability, ecological integrity, and the quality of essential resources. Strategies for sustainable management include conserving essential soil components, minimizing erosion, balancing production with environmental needs, and making better use of renewable resources. In this regard, soil health is a major indicator of sustainable management. Criteria for indicators of soil health are useful in defining ecosystem processes and sensitivity to managements and climatic variations and in integrating physical, chemical and biological soil properties. Numerous experts *e.g.* agricultural specialists, producers, conservationists, and policy makers, etc might extensively need those criteria and data for sustainable management practices. Although soils gain certain biological, chemical and physical properties within a given ecosystem, the ultimate determinant of soil productivity, sustainability and health is the land manager. The assessment of health and quality of soil is the primary indicator of sustainable management and environmental remediation. Examples given include approaches for assessing soil health, defining the economic and environmental sustainability of land management practices, and translating our science into practice.

Environmental services, particularly hydrological response and soil erosion control, can be managed effectively only at larger landscape scales. Research at the watershed scale is critical in the tropical regions, and given that projections indicate that eastern and southern Africa, and Central America will be critically short of water in the coming decades, extending TSBF-CIAT's research agenda into this area is warranted. Research projects funded by the Water and Food Challenge Program for the Volta in West Africa basins and on the Quesungual systems in Central America are providing the opportunity to address constraints related to water and its interaction with soil fertility and other environmental challenges. Research conducted with partners in regional networks and consortia and the GEF-UNEP funded BGBD project is contributing to development and promotion of sustainable land management (SLM) practices.

To see ISFM principles applied by a wide variety of actors at scales ranging from the farm level to the national or continental levels means addressing the problems of how to use knowledge gained at one scale to interpolate or extrapolate knowledge for decision making at another scale. In recent years TSBF and other natural resource management programs have confronted the challenge of extending their research findings for successful impact on farm. Conveying the numerous components and complexity of interactions involved in natural resource management is very different from the extension of new crop varieties through demonstration plots. In the latter, the results are quick and easy to see, whereas the results and possible benefits of natural resource management strategies may not be readily apparent and often take time to manifest themselves. The rise of the participatory movement in agricultural research has also emphasized the importance of responding to farmers' perceptions and needs rather than assuming that formal science provides solutions in its own right.

Key research questions

1. What is the minimum set of social, economic and biophysical indicators for preventing and reversing land degradation?
2. What are the drivers of land degradation?
3. Does hot-spot management provide a driver for wider-scale investment in ISFM?
4. What are the stakeholders, technologies and incentives necessary to enable SLM?
5. What are the global benefits (ecosystem services) from SLM?

Highlights

- Since a wide range of biophysical (e.g. climate, soil fertility, etc.) and socio-economic variables (e.g. preferences, prices, production objectives etc.) influence the use of legumes in smallholder systems, the 'socio-ecological niche' concept provided the framework through which the major biophysical and socio-economic constraints to legume adoption could be simultaneously identified and addressed. The socio-ecological niche, in any given region of agricultural activity, is created by the convergence of agro-ecological, socio-cultural, economic and ecological factors, to describe a multidimensional environment for which compatible technologies can be predicted. Two case studies demonstrated its practical significance.

- A simulation model that operates at field scale (DYNBAL-N: DYnamic simulation of Nutrient BALances) was used to understand the mechanisms leading to differences in resource use efficiency within a farm. When tested against a wide range of maize yield data from on-farm measurements undertaken in western Kenya, reasonably accurate predictions were obtained. Simulation results indicated that the use efficiencies of the biophysical resources such as radiation, water and N varied across different fields of the farms, and were strongly affected by management decisions and soil fertility status.

- In a set of trials in Central Kenya, evaluating the short- to long-term influence of organic resource quality on the quality and turnover of the soil organic matter pool, the fine-textured soil at Embu was more responsive to the input treatments than the coarse-textured soil at Machanga. Based on the results from Embu, the macroaggregate and microaggregate within macroaggregate fractions appear to be the most sensitive fractions to residue inputs. Additionally, residue quality had no effect on C and N contents indicating that quality may be less important than quantity for soil organic C and N stabilization in this soil.

- Population pressure and the need to maintain household food supplies have led to increase in land use intensity and natural resources extraction practices that degrade the environment in the savannas of northern Nigeria. This notwithstanding, some agricultural production practices were found to be environmental.

- Proposed the application of bio-char (charcoal or biomass-derived black carbon (C) to soil as a novel approach to establish a significant, long-term, sink for atmospheric carbon dioxide in terrestrial ecosystems and to deliver immediate benefits through improved soil fertility and increased crop production.

- Assessed the environmental and socioeconomic effects of a Payment for Environmental Services scheme in Pimampiro, Ecuador.
- Applied hydrological modeling to quantify environmental services in Andean Watersheds of Altomayo and Jequetepeque in Peru and Ambato in Ecuador.
- Conducted a critical analysis of experiences with "payments for environmental services" (PES) in Latin America and identified compensation schemes that would promote rural investment and thus contribute to the development of Andean communities and the conservation of environmental services.
- For a CDM (clean development mechanism) project to use carbon trading for promoting sustainable land management (SLM alternatives) that is in progress for land use conversion through silvopastoral systems and reforestation of marginal lands in the Caribbean savannas of Colombia, the team established the boundaries of the eligible target areas, characterized the baseline from the socioeconomic and carbon stock perspective and conducted ex ante calculation of net anthropogenic GHG (greenhouse gas) removal by silvopastoral and commercial forest systems.

Output target 2007

ü *Decision tools (GEOSOIL; Decision Tree) available for land use planning and targeting production systems in acid soil savannas*

Published work

S. Zingore, and K.E.Giller (2006) Long-term dynamics of soil organic matter and its ^{13}C signatures along cultivation chronosequences on contrasting Zimbabwean soils. Proceedings of the IAEA/FAO Special Workshop. World Congress of Soil Science, Philadelphia, USA.

Abstract: Soil organic matter (SOM) is crucial to the sustainability of smallholder agriculture that relies heavily on nutrient mineralized from organic matter due to small amounts of fertilizers used. Long-term changes in soil organic carbon and nitrogen were measured on fields cultivated for different ages after woodland clearance for smallholder farming on three different soils: Kalahari sand (5% clay + silt), granitic sand (12% clay + silt) and a red clay soil (50% clay + silt). A commercial farming site characterized by high external inputs was also studied on the red clay soil. Soil organic carbon (SOC) contents under reference woodlands were largest (53.3 t C ha^{-1}) in the red clay soil, followed by the granitic sand (22.8 t C ha^{-1}) and least (19.5 t C ha^{-1}) in the Kalahari sand. Cultivation under smallholder management induced rapid loss of SOC, resulting in fields cultivated for less than 5 years. New equilibrium was attained within 10 years on all soils. Greatest losses occurred in soils that initially contained most carbon and nitrogen in the order: red clay (22.4 t C ha^{-1}) > granitic sand (13.2 t C ha^{-1}) > Kalahari sand (10.6 t C ha^{-1}). On the clay soil, commercial farming with intensive use of mineral fertilizers and incorporation of maize stover led to more gradual decline: at equilibrium, contents of carbon and nitrogen were 15 t C ha^{-1} greater than on smallholdings with similar soil and climate. In the Kalahari sand, the ŭ^{13}C value of organic C remained constant after woodland clearance, and maize contributed less than 10% of the total C even after 55 years. The ^{13}C signature increased slightly with increasing duration of cultivation by smallholders in the granitic sands and red clay soil where maize contributed 29% and 35% of the C at equilibrium. Under more productive commercial farming, the carbon derived from maize accounted for 50% of the total after 10 years of cultivation and 67% at equilibrium. The persistence of woodland carbon in the sandy soil is attributed to chemical stabilization resulting from large concentrations of lignin and polyphenols in the tree litter, or as charcoal.

P. Tittonell, S. Zingore, M.T. van Wijk, M. Corbeels, and K.E. Giller (2006) Nutrient use efficiencies and crop responses to N, P and manure applications in Zimbabwean soils: Exploring management strategies across soil fertility gradients. Field Crops Research 100: 348-368.

Abstract: The spatial variability in crop yields commonly observed in smallholder farms of sub-Saharan Africa is often caused by gradients of declining soil fertility with increasing distance from the homestead. This heterogeneity means that recommendations based on regional soil surveys are of limited value. The variability in soil qualities within farms must be considered when designing management strategies, and their feasibility analysed by integrating results at the farm livelihood scale. For this purpose, we have developed the model FARMSIM, a dynamic bio-economic model for analysis and exploration of trade-offs in resource and labour allocation in heterogeneous smallholder farms. Focusing on farm-scale strategies, the approach to simulation of soil and crop processes in FARMSIM (the sub-model FIELD) is designed to be simple, but to keep the necessary degree of complexity to capture heterogeneity in resource use efficiencies. To test our approach, the sub-model FIELD was calibrated against chronosequences of woodland clearance in three agroecological zones of Zimbabwe (with soil textures of 3, 10, 35% clay), and used to simulate: (i) the creation of soil fertility gradients, and (ii) different strategies of N, P and manure applications to maize and soyabean rotations in homefields and outfields of smallholder farms on clayey and sandy soils. The results of the simulation of management strategies were

tested against on-farm experimental data from Murewa, Zimbabwe. The model produced satisfactory predictions (r^2: 0.6–0.9) of long-term changes in soil organic C, of crop responses to N and P and of nutrient use efficiencies across a wide range of yields and different field types. This demonstrated the broad applicability of the model despite the sparse data required for initialisation. However, the model results were less accurate in predicting crop responses to N and P applications in the outfields on sandy soils. Experimental evidence indicated yield limitation by Ca and Zn deficiencies in highly depleted outfields on sandy soils, which were not included mechanistically in the current version of FIELD. Repeated applications of 16 t ha^{-1} year^{-1} of manure allowed larger responses to applied N and P after 3 years of experimentation; such a corrective effect of manure was simulated to be due to improved N and P recovery efficiencies in the model. In combination with the experimental data, the simulation results suggested that soil fertility gradients affect nutrient use efficiencies, operating mostly on the efficiencies of nutrient capture rather than conversion. A typology of fields according to the type of management interventions needed is introduced, based on a generic application of FIELD with this parameterisation.

Completed work

Plant growth, grain yields and nutrient uptake in a maize-bean rotation under different rates of phosphorus fertilizer and chicken manure on a Colombian volcanic-ash soil (*Submitted to Eur. J. Agronomy*).

J. G. Cobo[1,2], O. Molina[1], J. Ricaurte[1], R.J. Delve[2], M.E. Probert[3], E. Barrios[1] and I. M. Rao[1] (2007)
[1]TSBF-CIAT, Colombia; [2]TSBF-CIAT, Zimbabwe; [3]CSIRO, Australia

High P fixation in volcanic-ash soils results in sub-optimal crop responses to P application under farmer practiced continuous cultivation. In this study, we evaluated two different sources of P-fertilizer, in two different experiments, at varying annual and residual rates of P application on a 4-year maize-bean rotation. The first experiment (TSP) had annual and residual applications of triple super phosphate, and the second experiment (CM) had annual applications of chicken manure. Shoot biomass and grain yields for maize and beans in both TSP and CM experiments were significantly different among treatments ($p<0.05$) and the response was proportional to increasing applications of P. At the first cycle, maize yields ranged from 0.4 (control) to 5.9 t ha^{-1} (160 kg P ha^{-1}) in TSP; while in CM maize yields ranged from 1.8 (control) to 6.5 t ha^{-1} (12 t manure ha^{-1}). Similarly, bean yields ranged from 30 to 780 kg ha^{-1} in TSP and from 343 to 1556 kg ha^{-1} in CM. As expected, crop biomass and grain yield diminished in residual treatments of TSP after the first cropping cycle, with lower P applications having the greatest decrease in crop production. However, effects from residual P treatments were higher than expected, possibly due to basal level of lime additions which presumably enhanced soil P-dynamics. From the annual applications of P in TSP experiment only 40 kg P ha^{-1} yr^{-1} significantly increased biomass and grain yield with time, and cumulative crop response on this treatment after 4 years was statistically similar ($p>0.05$) to cumulative response from residual treatment of 160 kg P ha^{-1}. This suggests that Ó40 kg P ha^{-1} year^{-1}, as triple super phosphate, could gradually build-up soil available P in these soils, and this practice is recommended against only one large P application at the beginning mainly due to lower risk involved. In the CM experiment, maize biomass and yields followed increasing P-inputs, which reached a plateau at 12 t manure ha^{-1}yr^{-1}. However, the second crop in the rotation (beans) had a greater crop response ($p<0.001$) with increasing applications of manure. Because farmers currently use 3-6 t manure ha^{-1} yr^{-1} in the rotation, it seems that they intentionally balance between satisfactory yields, with low cost of inputs (i.e. manure and labor), versus greater yields with greater costs and risks involved.

Response of maize-bean rotation to different rates of P fertilizer and chicken manure on a Colombian ash soil: IV Modelling response using APSIM.

R.J. Delve[1] and M.E. Probert[2] (2007)
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This paper reports progress in the development and testing of the APSIM modelling framework (Agricultural Production Systems Simulation Model; website www.apsim.info) towards functionality that can capture the release of N and P from various organic inputs, and for P from inorganic sources as well, and predict the growth of crops in situations where N and/or P is limiting. To this end the phosphorus routines in the Maize module have been incorporated in the APSIM Plant module so that the simulation of any crop that uses this module can, in principle, respond to P. In order to use this capability, the parameter set for any crop needs values for the critical P concentrations in the crop. These are used to estimate P demand by the crop to meet its daily growth requirements. Where the supply from soil is inadequate, the critical P concentrations determine the P stress being experienced, which is then used to reduce crop growth.

The experiments involving P inputs as fertilizer or chicken manure to a maize-bean cropping system were carried out to provide a data set that would be suitable for further testing of the model and extending its application to a different crop (namely bean). The environment and soil (a very high P-fixing Andisol) at the Colombian location is in strong contrast to the soil in semi-arid Kenya on which the model was first developed.

Site description: The experimental plots were located at CIAT's 'San Isidro' experiment farm in Pescador, in the Andean hillsides of the Department of Cauca, Colombia (2º48' N, 76º33' W, 1500 masl). The area has a mean temperature of 19.3ŬC and a mean annual rainfall of 1900 mm with bimodal distribution and two growing seasons. The soil is derived from volcanic ashes and is classified as an Oxic Dystropept (Inceptisol) in the USDA soil classification system and an Andic Dystric Cambisol in the FAO classification.

The model: The simulations were done with APSIM v3.6. The model was specified to simulate the experimental treatments involving TSP, CM and urea assuming common starting conditions for all treatments, there was no resetting of any variables between crops. Measured data were used to specify the soil characteristics for the APSIM SoilWat and SoilN modules. A major objective of the study was to test the transferability of the model. Thus as few modifications as possible were made to the parameters for the crop, soil P and manure modules.

Maize: As the maize cultivar had not previously been modeled using APSIM and to improve fit of the maturity date simulated by the model with known harvest dates we decreased the tt_emerg_to_endjuv parameter from 230 to 220. No changes were made to the critical P concentrations that had been used for modeling maize crops in Kenya.

Bean: There has been no previous experience of modeling the common bean grown in Latin America using APSIM. We used the APSIM Plant module with the Navybean parameter set selecting the cultivar specific values for 'rb_short'. Changes were made to the parameters tt_emerg_to_endjuv (increased from 250 to 300 to make the simulated crop mature later) and to y_hi_max_pot (increased from 0.45 to 0.50 to increase the maximum harvest index potential of the simulated crops). Both changes were made to try to improve the fit with the observed data. In order to model a P response in bean it was necessary to create the parameters defining the critical P concentrations in the components of the bean crop. These were derived from analytical data for samples from the experiment (available at flowering, pod-filling and maturity in 2002, pod-filling in 2003 and 2004). The other parameter required was p_supply_factor for navybean in the SoilP module.

Manure: The CM used each year in the experiment had been analyzed for total C, N and P and also ammonium- and nitrate-N. These values were used to specify the inputs of manure in the model. In the APSIM Manure module, manure is characterized in terms of the three pools corresponding with the fresh organic matter (FOM) pools of the Soil N module. In other studies attempts have been made to link these pools to proximate analyses of organic sources. Here we have assumed that the C was distributed in the ratio 0:0.5:0.5 between the three pools. Further we assumed that all pools had uniform composition of C, N and P.

Soil phosphorus: Soil P fractionation data were available only for the surface (0-10 cm) soil layer. We used the sum of resin P and bicarbonate Pi fractions as the estimate of labile P in soil. From this publication we estimated the P sorption for the surface layer to be 1000 mg kg^{-1} at the standard solution P concentration of 0.2 mg L^{-1}. No information was available for the subsoil layers. We have assumed that soil P decreases with depth and that P sorption increases in the subsoil.

Initial simulations used identical parameters in the Soil P module as were used to simulate a long-term experiment on an Alfisol in Kenya. However inspection of the output indicated that the rate of loss of availability of P applied as TSP was considerably faster on the Andisol than on the Alfisol. The parameter rate_loss_avail_P (fraction lost per year at 25^{o}C) was increased from 0.5 to 0.8 to improve the fit of the model to the observed data.

Crop yields: Observed and predicted crop yields through the eight seasons for selected treatments were compared. For the 12CM treatment there is good agreement for the maize crops that produced some 1300 g m^{-2} total biomass and 600 g m^{-2} grain each year. The grain yield for bean was predicted well in 2002 and 2004 but not in 2003. Total biomass for bean was over-predicted (this is explored in more detail below). The 2003 bean crop was severely affected by diseases caused by *Rhizoctonia solani* and *Colletotricum lindemuthianum* which delayed maturity well beyond the normal 88 days and seemingly reduced yields. The simulation of the treatment without added P has much smaller yields of maize and bean. Comparing this treatment with 12CM shows that the model predicted a large response to input of P in this soil. The experimental data for the control treatments in the two experiments (0CM and 0P) showed considerable variation. The observed data are the means of these two treatments. The other two treatments compared the effects of the one-time application of 160 kg P ha^{-1} as TSP with the annual input of 40 kg P ha^{-1}. In both cases there is good agreement between the observed and predicted data. For the 160P treatment the yield of maize in the first crop is close that for 12CM, but the residual effect is not sufficient to maintain high yields in later seasons. These were the findings that led to the use of the higher rate of loss of available P in the model. With the parameterization used the model predicts the declining yields rather well. In contrast, the annual application of 40P was inadequate to yield as well as 12CM or 160P in the first season, but through time this treatment improves to yield better than 160P in the 2005 maize crop. Again the model captures this effect well.

The model simulated the observed data very well despite the very few and minor changes made, showing the robustness of the model. This is also the first experience of modelling beans with APSIM and will become the first published example of extending P routines to beans.

GEOSOIL: A decision support tool for Land-use planning

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The Georeferenced System on Soil Quality Indicators (GEOSOIL) for the Colombian savannas was developed as a tool of support to the decision-makers in land use planning. It allows to store, consult and process soil data from different scales: plot, farm, community, municipality, department, region, and country. It operates from a database of ACCES 2000, composed by a series of structured tables with information at different hierarchic levels to allow the characterization of the soil. The morphological and analytical elements of the soil are combined to conform indicators of quality by a qualification system that allows visualizing the degree and the number of limitations that a soil could have for its use in agriculture. The degrees of qualification used were: (1) without limitation, (2) slight limitation, (3) moderate limitation, (4) severe limitation, and (5) very severe limitation. The quality of the soil is associated with the degree and number of limitations that diminish its productive capacity. In addition, GEOSOIL has modules in which the user can: (a) add or consult spacial characteristics and attributes of the soil; (b) visualize the interpretation of the soil quality indicators, grouped in limitation ranks; (c) determine the general capacity of the soil for a specific land use by means of the comparison between the nutrient supply capacity of soil versus the nutrient demand of the crop; (d) calculate the fertilization rates; (e) generate reports on the variability in depth of some characteristics, for one or more soils; and (f) map the results by means of a link with the Geographical Information Systems, in the specific case for free software MapMaker or Spring. The system also generates geoestatistical assessment to understand the spatial and temporal variability of the attributes that are being used as indicators.

GEOSOIL was developed as a land-use planning tool for the Colombian savannas. This tool allows decision-makers to compile, consult and process soil data at several scales of resolution (plot, farm, community and country). The morphological and analytical elements of the soils are combined to form indicators of soil quality and to qualify the constraints for different agricultural purposes (Figure 71). The system has several modules that deliver information regarding general capacity of a given soil type for a given land use based on major constraints and produce outputs that are linked to visual observation using mapmaker or Spring. The system in the form of a CD-ROM Series is available to NARS and private sector partners in Colombia.

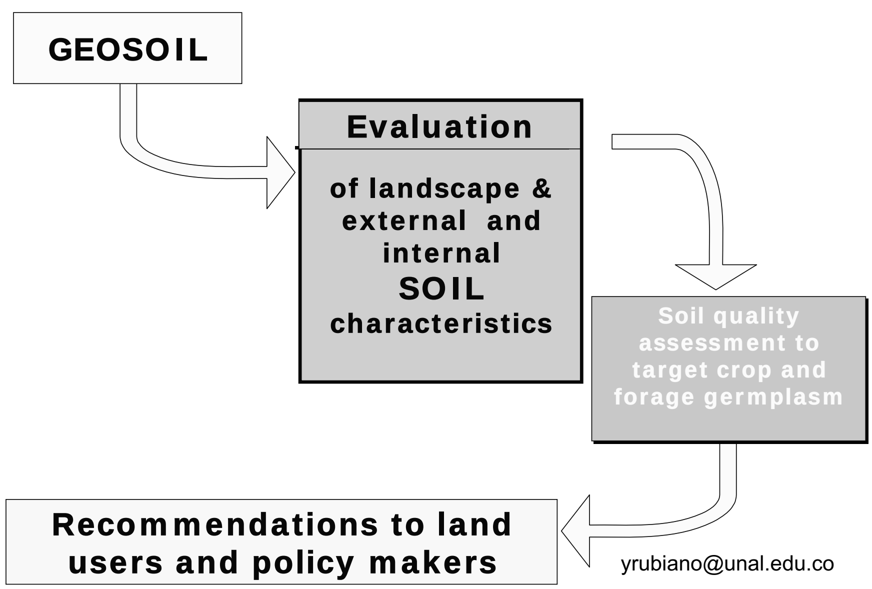

Figure 71. The components of GEOSOIL decision support system for land use planning.

Decision tree: A decision support tool developed to define land use alternatives in Colombian tropical savanna

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A decision support tree was developed by a group of researchers at CIAT to overcome land degradation problems and to improve agricultural productivity in the Colombian savanna soils. The decision tree provides an assessment to target the best land use possible based on soil texture, soil depth and topography characteristics. It was designed on both local and scientific knowledge from the acid soil savanna region of Colombia. This tool combines the use of both the SPRING and the MapMaker Popular as GIS packages and the Microsoft Access 2000 database software.

The results of the analysis are displayed through text and spatial reports. The maps for land use alternatives are generated based on soil unit characteristics (1:100.000 scale) of the soil map. The polygons or soil units in soil maps generally correspond to different groups of soils that can have different characteristics. The percentage that each soil represents in the polygon is indicated in the tables accompanying the maps. The polygons are colored according to the percentage of soil that is suitable for a given land use alternative (Figure 72).

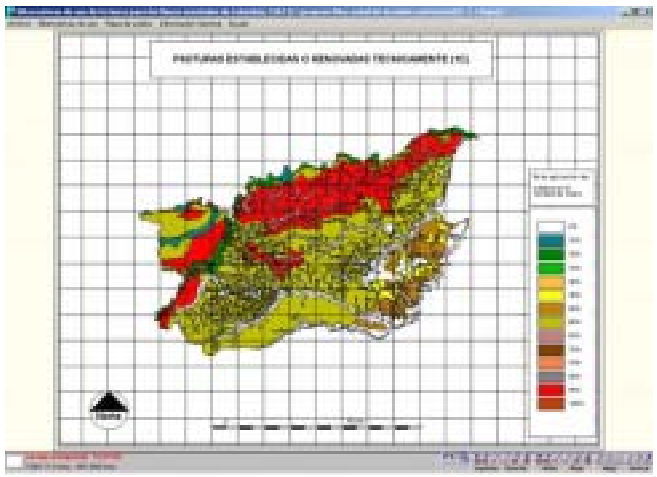

Figure 72. Mapping of areas recommended for improved pastures to be established or to renovate every 5 years, based on the percentage of suitable area within each soil unit.

The design of the database tool allows to modify the decision tree rules to apply to other locations. The system in the form of a CD-ROM Series is available to NARS and private sector partners in Colombia.

Output target 2007

ü ***Biophysical, social and policy niches in the landscape for targeting SLM technologies and enhanced ecosystem services identified and prioritized***

Published work

J. Lehmann[1], J. Gaunt[2] and M. Rondón[3] (2006). Bio-Char Sequestration in Terrestrial Ecosystems - A Review. Mitigation and Adaptation Strategies for Global Change 11: 403-427.

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Abstract: The application of bio-char (charcoal or biomass-derived black carbon (C) to soil is proposed as a novel approach to establish a significant, long-term, sink for atmospheric carbon dioxide in terrestrial ecosystems. Apart from positive effects in both reducing emissions and increasing the sequestration of greenhouse gases, the production of bio-char and its application to soil will deliver immediate benefits through improved soil fertility and increased crop production. Conversion of biomass C to bio-char C leads to sequestration of about 50% of the initial C compared to the low amounts retained after burning (3%) and biological decomposition (<10-20% after 5-10 years), therefore yielding more stable soil C than burning or direct land application of biomass. This efficiency of C conversion of biomass to bio-char is highly dependent on the type of feedstock, but is not significantly affected by the pyrolysis temperature (within 350-500^{o}C common for pyrolysis). Existing slash and-burn systems cause significant degradation of soil and release of greenhouse gases and opportunities may exist to enhance this system by conversion to slash-and-char systems. Our global analysis revealed that up to 12% of the total anthropogenic C emissions by land use change (0.21 Pg C) can be off-set annually in soil, if slash-and-burn is replaced by slash-and char. Agricultural and forestry wastes such as forest residues, mill residues, field crop residues, or urban wastes add a conservatively estimated 0.16 Pg C yr^{-1}. Biofuel production using modern biomass can produce a bio-char by-product through pyrolysis which results in 30.6 kg C sequestration for each GJ of energy produced. Using published projections of the use of renewable fuels in the year 2010, bio-char sequestration could amount to 5.5-9.5 Pg C yr^{-1} if this demand for energy was met through pyrolysis, which would exceed current emissions from fossil fuels (5.4 Pg C yr^{-1}). Bio-char soil management systems can deliver tradable C emissions reduction, and C sequestered is easily accountable, and verifiable.

Completed work

Soil Biota, Ecosystem Services and Land Productivity

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The soil environment is likely the most complex biological community. Soil organisms are extremely diverse and contribute to a wide range of ecosystem services that are essential to the sustainable function of natural and managed ecosystems. The soil organism community can have direct and indirect impacts on land productivity. Direct impacts are those where specific organisms affect crop yield immediately. Indirect effects include those provided by soil organisms participating in carbon and nutrient cycles, soil structure modification and food web interactions that generate ecosystem services that ultimately affect productivity. Recognizing the great biological and functional diversity in the soil and the complexity of ecological interactions it becomes necessary to focus in this paper on soil biota that have a strong linkage to functions which underpin 'soil based' ecosystem services. Selected organisms from different functional groups (i.e. microsymbionts, decomposers, elemental transformers, soil ecosystem engineers, soil-borne pest and diseases, and microregulators) are used to illustrate the linkages of soil biota and ecosystem services essential to life on earth as well as with those associated with the provision of goods and the regulation of ecosystem processes. These services are not only essential to ecosystem function but also a critical resource for the sustainable management of agricultural ecosystems. Research opportunities and gaps related to methodological, experimental and conceptual approaches that may be helpful to address the challenge of linking soil biodiversity and function to the provision of ecosystem services and land productivity include: 1) integration of spatial variability research in soil ecology and a focus on 'hot spots' of biological activity, 2) using a selective functional group approach to study soil biota and function, 3) using understanding about hierarchical relationships to manage soil biota and function in cropping systems, 4) using local knowledge about plants as indicators of soil quality, remote sensing and GIS technologies, and plant-soil biota interactions to help understand the impacts of soil biota at landscape scale, 5) combining new and existing methodological approaches that link selected soil organisms, the temporal and spatial dynamics of their function and their contribution to the provision of selected 'soil based' ecosystem services, and 6) developing local land quality monitoring systems that inform land users about their land's ecosystem service provision performance, improve capacities to predict and adapt to environmental changes, and support policy and decision-making.

Global Desertification: Building a Science for Dryland Development

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In this millennium, global drylands face a myriad of problems (e.g., land degradation, poverty) that present tough challenges (e.g., safeguarding biodiversity, protecting the culture of 2 billion people) to the research, management and policy communities.

Recent advances in dryland development, however, in concert with the integrative approaches of global change and sustainability science, suggest that these challenges can be confronted with renewed optimism. In this paper, we review recent lessons about the functioning of dry land ecosystems and the livelihood systems of their human residents, and introduce a new synthetic framework, the *Dry lands Development Paradigm* (DDP). The DDP, supported by a growing and well-documented set of tools for policy and management action, helps navigate the inherent complexity of desertification and dry land development, identifying and synthesizing those factors important to research, management, and policy communities.

Assessment of the environmental and socioeconomic effects of a Payment for Environmental Services scheme in Pimampiro (Ecuador)

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In 2000, a scheme of Payment for Environmental Services (PES) was created in the municipality of Pimampiro (Ecuador). The main purpose of the scheme is to facilitate payments from the urban water users to the households located in the Palahurco River micro-watershed, from where water is diverted towards the municipal aqueduct. The PES system was designed to protect native vegetation, as a means to protect both water quality and quantity during dry season. The payment amounts range from \$12 $year^{-1}$

ha^{-1} to \$6 year^{-1} ha^{-1} depending on the type of land cover. Thus for a conserved hectare of primary forest or *paramo* the household will receive \$12 year^{-1} while for a hectare of intervened forests or *paramo* will be paid \$6 year^{-1}. Although this scheme started five years ago, the impact of it on the environmental service has not been quantified. The scheme is monitored from the land cover perspective but not from the hydrological service itself.

CIFOR has been collaborating with this experience because from the conceptual side, it is one of the few decentralized schemes in Latin-America where user and providers are well identified and there is a payment transaction between them. However, because there is no scientific evidence of the provision of the service, CIAT was contracted to: 1) analyze how water and sediment yield varies in the Palahurco micro-watershed under different land use scenarios; 2) determine what are the effects of the PSA scheme on the socioeconomic and environmental baseline; and 3) determine to what extent the payment amounts are an economic incentive for the households and therefore, constitutes an incentive for the conservation of forests and paramo ecosystem.

CIAT team conducted the analysis for three general land use scenarios: 1) current land use; 2) all current agricultural areas are converted to forest; and 3) vulnerable forestlands surrounding the agricultural frontier are converted into agricultural areas. The evaluation of these three scenarios was conducted by means of hydrological modeling through which Hydrological Response Units (HRU) were defined. The identification of these units permitted to link them with the impact on sediment and water yield. Figure 73 shows the impacts of different land use scenarios.

The main findings of the analyses were:

- The permanence of forest cover avoids actual increments of the sediment yield. If this land cover is replaced by the rotation of pasture-potato-pasture, the sediments will be increased by about three times (Figure 73). With respect to water quantity, it does not vary as high as it could occur with sediments. Thus, the effect of land use change on water quantity will be small. However, the replacement of forest will affect the base flow which is critical during the dry season.
- Although the current payment amounts are relatively low, they do represent an economic incentive. This is explained by the fact that the opportunity cost of conserving these areas is practically equal to what they receive through the conservation payments. The opportunity cost of using these areas for agriculture was calculated assuming a deforestation rate of 0.5 ha year^{-1} and the current production costs and prices of the products (Table 60)
- In terms of additionality, there is a potential to reduce current sediment yield in the micro-watershed as land use change in current agricultural areas could lead to a considerable reduction. Thus, if these areas are replaced by forestry as a land use, the current sediments could be lowered by about 68%. However, this change in land use will require an increment in the payment amounts as the opportunity costs will be higher.

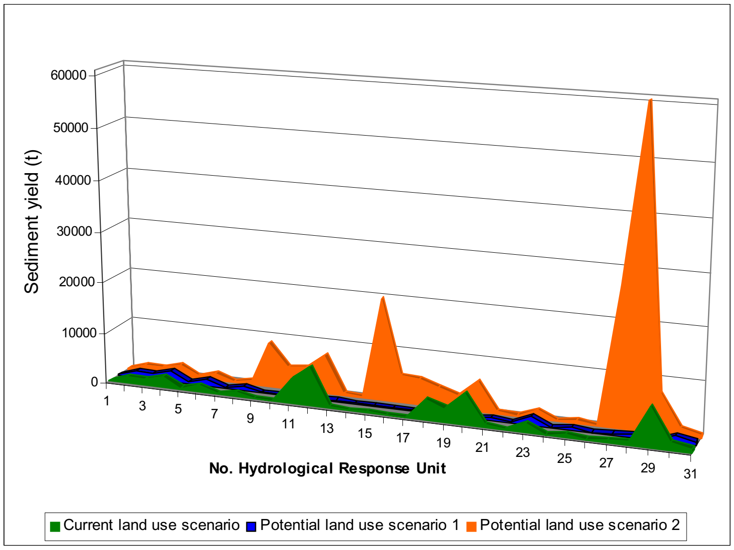

Figure 73. Impact of HRUs on sediment yield.

Table 60. Net income (US$) for a typical farm in the Palaurco River micro-watershed, under three different land use scenarios.

	Scenario 1*	**Scenario 2***	**Scenario 3***
Net Income (*r*=5%)	$26,690	$33,075	$28,172
Net Income (*r*=15%)	$15,569	$18,154	$16,532
Net Income (*r*=20%)	$12,343	$13,951	$13,148

Note: *r* is discount rate. Calculation was made for a 10 year-period.
Scenario 1*: Typical farm with 20% of farmland in agriculture and 80% in natural forest.
Scenario 2: Typical farm with 20% of farmland in agriculture, 80% in natural forest and 0.5 ha are incorporated to agriculture every year (deforestation rate 0.5 ha $year^{-1}$).
Scenario 3: Typical farm with 20% of farmland in agriculture, 80% in natural forest and received a payment for conserving the forested area.

Hydrological modeling to quantify environmental services in Andean Watersheds: Altomayo and Jequetepeque watersheds (Peru) and Ambato (Ecuador)

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The Jequetepeque and Altomayo watersheds in Peru, and the Ambato watershed in Ecuador, are study sites of the project 22 "Payment for environmental services" of the WFCP. To quantify the main water-related environmental externalities, hydrological modeling has been applied for each of the watersheds. The main quantified externalities are the sediment and water yields under different land use scenarios. For this purpose, the project has conducted the modeling in collaboration with the local partners who have been trained for using SWAT (Soil & Water Assessment Tool) by the project team. Thus, the analysis for the Jequetepeque and Altomayo watersheds was conducted in collaboration with local technicians and in Ambato (Ecuador) with the local partner, Randi Randi Corporation.

For each watershed, the Hydrological Response Units (HRU) were determined and prioritized according to their contribution with sediments and water. To determine these units, an overlap of the soil unit map, topography, land cover map, and daily climatic information was made. To determine the hydrological response of each one of these units, water-related soil characteristics, land cover attributes, slopes, and daily climatic information (precipitation, temperature, radiation, wind speed, etc) were specified into the model. With this information water movement through the soil profile and water flows for the whole watershed were simulated. For the case of Ambato watershed, also glacier melting effect was simulated in order to include the effect of Tungurahua volcano in water flows.

In Figures 74 and 75, the variations in water and sediments for the Ambato watershed are shown. This analysis shows the impact of two land use scenarios: the current land use scenario and a potential land use scenario, where natural *paramo* areas are replaced by potato crops. These hydrological responses were also obtained for each HRU in the three watersheds that were analyzed.

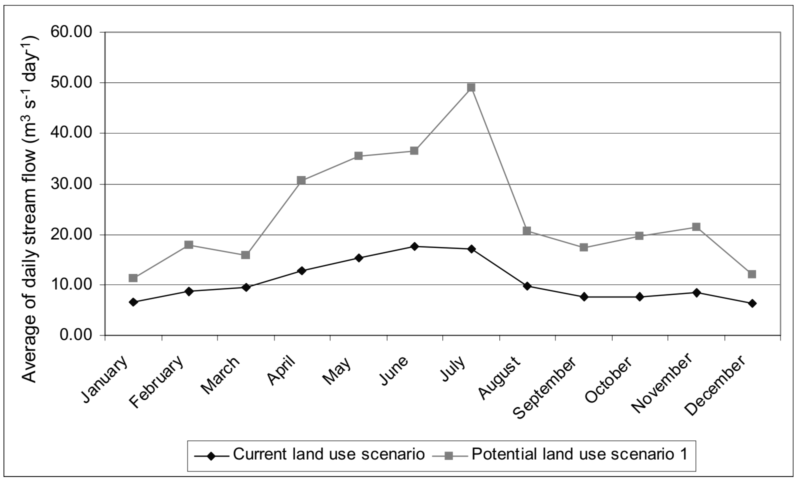

Figure 74. Impact on stream flow of changing natural *paramo* cover by potato crops.

These results will be used during 2007 to valuate the environmental impacts. The *trade offs* between environmental services and socioeconomic impacts of land use change scenarios will be also assessed.

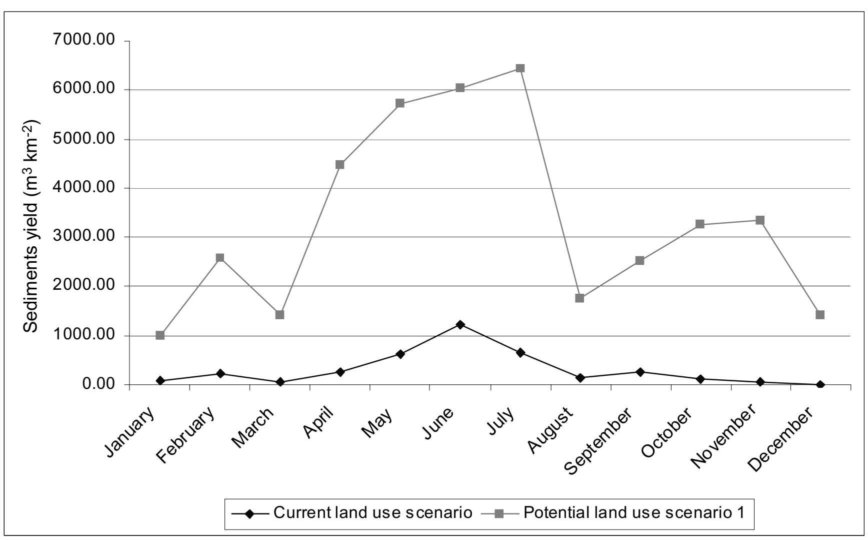

Figure 75. Impact on sediments yield of changing natural *paramo* cover by potato crops.

Output target 2008

ü *Methods for socio-cultural and economic valuation of ecosystem services developed and applied for trade-off and policy analysis used in at least in 2 humid and 2 sub-humid agroecological zones*

Published work

M. Quintero[1] and R.D. Estrada[2] (2006) Payment for environmental services in Latin America and its perspectives in the Andes, a vision from the practice (In Spanish: Pago por servicios ambientales en Latinoamérica y sus perspectivas en los Andes. Una visión desde la práctica). Serie Contribuciones para el Desarrollo Sostenible de los Andes. No. 4. Septiembre 2006. Lima, Perú. 46 p): Monograph.

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Many small farms operate in the mountainous areas of the Andean Region. But in these areas, the value of social and environmental externalities is often greater than the increases possible in income through agriculture and livestock production. This generates a potential for stimulating changes in agricultural management practices and/or land use so that resources may be transferred from the rest of the economy to the rural sector. Hence, since 1998, the Policy Division of the Consortium for the Sustainable Development of the Andean Ecoregion (CONDESAN) has been proposing that environmental externalities be the motor to stimulate rural investment and change the dynamics of development for the Andean mountains.

Several types of mechanisms exist whereby resources can be transferred between sectors. The simplest to implement are direct governmental subsidies for farmers. However, they are also the most difficult for documenting impact. Other mechanisms include payments for environmental services through bonuses for specific externalities (e.g. carbon capture), which are traded on world markets through stock exchanges.

Each mechanism demands a different exactitude in showing the causal relationships between change in land use and its impact on a given externality, the value of the service, and the distribution of benefits among the various actors intervening in the transaction. In general, markets for environmental services are poorly developed and correspond more to segmented local markets, with world markets being less important. Hence, these markets are rarely connected, substantially increasing transaction costs, which often become higher than the value of payments and requiring donations to cover such costs. This is because what is being paid for is not the environmental service but the land uses that generate it. This means we must first understand the causal relationships between use and service. In this regard, transaction costs are high because the value of the service is closely related to the spatial location and temporal evolution of alternative land uses. These elements are fundamental for hydrologic services (water production and reduction of sediments), precisely those that, currently, have the most potential for being compensated for in the Andes.

This critical analysis of experiences with “payments for environmental services” (PES) in Latin America aims to identify compensation schemes that would promote rural investment and thus contribute to the development of Andean communities and the conservation of environmental services. The following steps are therefore carried out:

- To discuss the relevant theoretical framework for developing PES schemes and markets for environmental services.
- To review research conducted in Latin America on PES mechanisms or markets for environmental services.

- To describe the fundamental elements for increasing the probability of successfully using environmental externalities as a motor for development and conservation. Hence, to do this, both the reviewed experiences and those of CONDESAN's are used as a basis for analyzing environmental externalities, the trade off between them, and the transaction costs incurred for demonstrating the causal relationships.
- To develop a theoretical and operational proposal for the type of exchange mechanism that would be the most efficient for small farmers in the Andes, taking into account the trade off between farm income and environmental benefits. The use of externalities to generate dynamics of development with the poorest farmers is analyzed. We also evaluate how compensation mechanisms change as this priority becomes involved in analyses.

In this paper, we critically examine the progress made by the reviewed experiences in Latin America. The paper does not attempt to describe each of these experiences, but to point out their principal characteristics of operation and impact, and thereby analyze the following questions: (a) do these experiences correspond to PES schemes? (b) do they contribute to development objectives and/or conservation? (c) are they based on political negotiations and/or technical analysis on the quantity and value of the externality? and (d) do they provide evidence on the relationships between environmental services and the land use or management practices promoted with the PES scheme?

Work in progress

Land use conversion through silvopastoral systems and reforestation of marginal lands in the Caribbean savannas of Colombia. A CDM project to use carbon trading for promoting SLM alternatives

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In 2005, a CDM project to recuperate degraded lands of the tropical savannas of northern Colombia was initiated. This project aims to enhance the productivity and natural resource base of 2,600 hectares of degraded lands by implementing silvopastoral systems and reforestation. The project is developed by the Centro Internacional de Agricultura Tropical (CIAT), the Colombian National Agricultural Research Organization (CORPOICA), and the Environmental Corporation of the Sinu and San Jorge Rivers (CVS).
The silvopastoral system was designed by the Colombian National Agricultural Research Organization (CORPOICA) and consists in the planting of forage shrubs very well adapted to the region (*Gliricydia sepium, Cresentia Cujete* and *Leucaena leucocephala*) with high-value timber species (*Pachira quinata*, *Switenia macrophylla* and *Tabebuia rosea*). For the reforestation areas three native tree species (*Tabebuia rosea, Tectona grandis,* and *Bombacopsis quinatum*) and the exotic specie *Hevea brasiliensis* will be planted.

In 2006, the project has continued its trajectory by accomplishing the different requirements needed for the negotiation of the project. After the completion of the Project Idea Note (PIN) and the Carbon Finance Document (CFD), the project team worked intensively in establishing the boundaries of the eligible project areas, the characterization of the baseline from the socioeconomic and carbon stock perspective and in the ex ante calculation of net anthropogenic GHG removal by silvopastoral and commercial forest systems. In general the IRR calculated for the project is around 20% and when the social benefits caused by income and employment are included, that is, all benefits not collected directly by the producers but received by society; the project IRR is around 30%. The ex ante calculation of GHG removals resulted in 246992 CO_2-e to 2017 and 1015839 CO_2-e to 2037. The offset of these carbon emission reductions (CERs) was concretized through an Emission Reduction Purchase Agreement (ERPA) signed with the BioCarbon fund.

Although the proposed project activities can be profitable by themselves, the support from the BioCarbon fund facilitates the initial investments and the participation of CVS as the investor in this project. CVS acts as a partner in the enterprise, absorbing risks and guaranteeing a good profitability to the beneficiaries. It also partly finances complementary activities that generate revenues from the first three years to mitigate the impact on farmer’s cash flows.

Output target 2008

ü ***In at least four of the countries participating in the BGBD project, policy stimulated to include matters related to BGBD management, and sustainable utilization.***

Progress towards this output target will be reported next year.

Output target 2009

ü ***30% of partner farmers in pilot sites used SLM options that arrested resource degradation and increased productivity in comparison with non-treated farms***

Progress towards this output target will be reported next year.

Output target 2009

ü ***75% of stakeholders in target areas have an improved capacity for collective action and local policy negotiation and implementation of integrated land use practices using integrated agricultural research for development***

Progress towards this output target will be reported next year.

Output target 2009

ü ***The benefits of community-based watershed management innovations quantified and disaggregated by wealth and gender***

Progress towards this output target will be reported next year.

Progress towards achieving output level outcome

∉ *Principles of sustainable land management integrated in country policies and programs*

This output is aimed at restoring degraded agroecosystems to economic and ecologic productivity, while recovering the function of such lands as providers of a range of ecosystem goods and services. Tools developed over the past few years are starting to be used by farmer associations to better plan the use of their land. An example of that is the use of GEOSOIL decision support system for planning oil palm in the acid soil savannas of Colombia. Important advances were made towards the development and testing of methods for assessing and putting value on environmental services, particularly at the Fuquene Watershed in the Colombian Andes. Intensive field monitoring coupled to the use of special software allowed to identify the most suitable options at the watershed scale to balance productivity and socioeconomic profitability and the maintenance of ecosystem functions. Methods were refined to include the potential to generate tradable Carbon in the watershed and how this could facilitate the adoption of desirable land use management practices. The use of similar approaches allowed to define that shaded coffee is the most suitable land use option for farmers in the Altomayo Watershed in Peru to provide not only income and job generation, but also reduced impact on the environment. In a contrasting drier agroecosystem, the steepland region of Lempira in Honduras, significant advances were made towards understanding the drivers behind the adoption of the Quesungual slash and mulch agroforestry system. This knowledge is already being used to promote the expansion of the systems into an even drier region in Nicaragua. The potential of two key ecosystems in Latin America, the Amazon rainforest and the acid soil savannas, to serve as net sinks for atmospheric carbon and to play a role in mitigating climate change, was assessed.

The interactions between the policy environment and the socio-cultural and economic condition have been addressed through studies that look for enabling environments. By this the support systems are meant to address financial and technological infrastructure as well as the extension services for scaling out win-win land use and management alternatives. Research showed that specific strategic alliances are required for the poorest farmers to benefit from financial mechanism that would allow them to adopt new technologies.

Progress towards achieving output level impact

∉ *Reversing land degradation contribute to global SLM priorities and goals*

A special project to rehabilitate extensive areas of degraded lands in the Caribbean savannas from Colombia through the use of silvopastoral systems and reforestation with native species was successfully negotiated with the Biocarbon Fund. This is the first initiative to use Carbon trading to cover part of the cost of the actions required to stop and reverse land degradation. Though this is a long term initiative, expected impact on the livelihoods of poor rural communities, including native Indians is very high. Outcomes from the special projects mentioned above are helping to set the scene for the articulation of future plans for payment of environmental services in rural areas. Governments, particularly in Latin America could use the outcomes of such initiatives to define policies to reverse land degradation at local and regional levels. With the partnership of a large interdisciplinary team, CONDESAN is aiming to provide local and regional authorities with guidelines to help policy makers in the definition of incentives and mechanisms to include payment from environmental services as part of the local land use planning.