Output 1

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

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Rationale

Sustainable agriculture is viewed here from a systems perspective in which the agroecosystem interacts with the atmospheric system and the hydrological cycle as well as with the social and economic systems of the community where it is practiced. This conceptual model transcends the classical boundaries of the biophysical sciences and requires integration with economics, sociology, anthropology and political science. In this context, output 1 deal with developing a mechanistic understanding of the physical, chemical and biological processes regulating soil fertility as a result of intensification and diversification of cropping systems and the recuperation of degraded lands. Nutrient cycling and organic matter dynamics are undoubtedly key drivers of agroecosystem function. There is increasing need, however, to address the issue of scale-dependence of different soil processes ranging from processes at the plant's rhizosphere, to nutrient gradients within farms or greenhouse gas emissions at the landscape scale.

The processes of land conversion and agricultural intensification are a significant cause of biodiversity loss, including that of below ground biodiversity (BGBD), with consequent negative effects both on the environment, ecosystem services and the sustainability of agricultural production. Documentation of BGBD, including the biological populations conserved and managed across the spectrum of agricultural intensification, is an essential component of the information required for assessment of environment-agriculture interactions, as is the evaluation of the impact of agricultural management on the resource base, particularly that of the soil. Soil organisms contribute a wide range of essential services to the sustainable function of agroecosystems among which the biological control of pests and diseases ranks high. The combination of soil fertility and pest and disease management approaches is likely to be a unique opportunity to exploit synergies for the benefit of crop productivity.

Improving the natural resource base without addressing issues of marketing and income generation is often the reason for the lack of adoption of improved farming practices. Participatory approaches have shown considerable potential in facilitating farmer consensus about which soil related constraints should be tackled first. Consensus building is an important step prior to scaling up and out and collective action by farming communities in integrated soil management at the landscape scale. Integration of local and scientific knowledge to develop an integrated or "hybrid" knowledge and thus increased relevance is an overall strategy for sustainable soil management.

Key research questions:

1. Can temporal and spatial heterogeneity at the farm, community, and landscape scale levels be exploited with sustainable land management (SLM) technologies that enhance production and/or improve ecosystem services?
2. How does loss of below-ground biodiversity (BGBD) relate to increasing land use intensity and what are the effects on ecosystem function?
3. To what extent is conservation agriculture applicable to different farming systems?
4. How can we build increased capacity for ISFM by integrating local and technical knowledge?
5. What are the socio-cultural and economic conditions, policies and institutions that influence ISFM?

Milestones 2005

- **Documentation and analysis of farmers'perceptions, preferences, economics and information flow pathways and use of local knowledge within research to extension linkages**

Intensive work with nearly 20 farmers' groups in Western Kenya, and extensive work with farmer groups at other TSBF and AFNET sites elsewhere in Africa, has documented a diversity of rich, context-specific knowledge, priorities, and constraints of smallholders relating to soil fertility management. An innovative community-based learning strategy has successfully stimulated the growth of a "dynamic expertise" that combines local and outsiders' soil fertility management knowledge, with a view towards scaling this expertise up and out of the initial research sites using local networks and institutions.

South-South collaboration through the transfer of concepts and methodological approaches to integrate local and technical knowledge about soils and their management from Latin America to east Africa had measurable impacts on: a) the formal education sector (Makerere University – Uganda), b) a regional research organization (African Highlands Initiative, AHI - Tanzania) and c) a global NGO (CARE-Kenya - Kenya).

- **Role of social differentiation in the creation and maintenance of soil fertility analyzed**

Robust techniques for analyzing heterogeneity of socio-economic and biophysical factors influencing soil fertility management and soil fertility outcomes have now been developed, tested, and applied in a diversity of environments and socio-cultural settings. Strong relationships and patterns of local diversity have emerged, but issues of intra-household differentiation and gender-driven processes of resource access and use could still benefit from more attention. Student theses incorporating these approaches are now well underway.

Highlights

- In a set of medium to long-term trials in the West-African savannas, it was shown that the functioning of the often hypothesized 'safety-net' of trees in a tree-crop intercrop depended on (i) the tree species and on (ii) the presence of a subsoil of suitable quality, i.e., clay enriched and with high Ca saturation. Especially, *Senna siamea* trees were shown to enrich the topsoil with Ca on soils with a clay-enriched subsoil.
- In a long-term hedgerow intercropping trial in West-Africa, it was shown that application of prunings of *Senna siamea* in combination with limited amounts of fertilizer can sustain maize yields above 2.5 tons per hectare for over 15 years. These yields also showed the lowest between-season variation. Sole application of fertilizer resulted in highly variable crop yields between seasons.
- In the Sudan savanna in Burkina Faso, annual application of manure was shown to mitigate the negative effect of ploughing and hand hoeing on soil organic carbon related properties and can therefore contribute to the sustainability of agricultural systems in the Sudano-Sahelian zone.
- In Western Kenya, plant height measurements, taken at any moment after maize flowering, were shown to be good estimators for maize grain yield. This approach proved also a valuable tool to discuss yield variability with farmers.
- Short-term laboratory mineralization data supported the existence of 3 classes of organic resources instead of 4 originally proposed by the Decision Support System for organic N management. It was also shown that direct prediction of decomposition and mineralization from

NIR was faster, more accurate and more repeatable than prediction from residue quality attributes determined using wet chemistry.

- In evaluating the impact of inherent soil properties and site-specific soil management in Western Kenya, it was observed that both above factors explained the variability found in soil fertility status between farms. Texture explained the variation observed in soil C and related total N between sub-locations, whereas P availability varied mainly between farm types as affected by input use. The internal heterogeneity in resource allocation varied also between farms of different social classes, according to their objectives and factor constraints.
- In Western Kenya, in-vitro techniques have shown a high variability within the soybean genepool for triggering suicidal Striga germination. This trait can be used to select specific soybean varieties to be integrated in soybean-cereal rotations in Striga-infested areas.
- Identified, validated, and applied local and technical indicators of soil fertility quality using replicable methodology under smallholder conditions in Kenya to support farmers' experimentation with soil fertility management options.
- Community-based learning and communication strategies to support ISFM research were evaluated collectively by farmers and researchers at a special workshop (June 2005), which contributed to greater farmer involvement in the planning and implementation of the renewed project's second phase.
- The "land degradation" concept was critically reviewed and re-interpreted through dialogue between local and scientific knowledge, updating and prioritizing ISFM interventions appropriate to diverse small-holder conditions.
- Synthesis volumes on the Conservation and Sustainable Use of BGBD published by country teams (Kenya, Indonesia, India) and abstracts from all the country teams' activities were compiled and presented at the annual meeting held in Manaus, Brazil.
- South-South collaboration through the transfer of concepts and methodological approaches to integrate local and technical knowledge about soils and their management from Latin America to east Africa had measurable impacts on: a) the formal education sector (Makerere University – Uganda), b) a regional research organization (African Highlands Initiative, AHI - Tanzania) and c) a global NGO (CARE-Kenya - Kenya).
- In medium-term trials in Colombian Andean hillsides it was shown that the *Tithonia diversifolia* slash/mulch fallow system could be the best option to regenerate soil fertility of degraded volcanic-ash soils after continuous cassava cultivation. Soil parameters most affected by slash/mulch fallow systems included soil total N, available N (ammonium and nitrate), exchangeable cations (K, Ca, Mg and Al), amount of P in the Ludox light fraction, soil bulk density and air permeability, and soil macrofauna diversity.
- Showed that the superior adaptation of *Calliandra calothyrsus* as planted fallow species to infertile soil conditions in Cauca, Colombia is related to its ability to develop fine roots in subsoil layers.
- Field studies on residual P response of maize and bean in volcanic ash soils in Cauca region of Colombia suggested that application of $\geq$ 40 kg P ha^{-1} $year^{-1}$ could gradually build-up soil available P and this practice is better than one time application of large amount of P.
- A methodological approach was developed to study the origin of soil aggregates separated according to visual criteria and determined by comparing their specific organic matter signatures assessed by NIRS to signatures of biogenic structures produced by soil ecosystem engineers.
- Studies in Colombia and Nicaraguan hillsides showed the high potential of NIRS for evaluating soil quality in large areas, rapidly, reliably and economically, thereby facilitating decision-making with respect to soil management and conservation.
- High earthworm population was observed under the Quesungual slash and mulch agroforestry system of South-Western Honduras and it was mostly localized near trees. In contrast, ant populations were not associated with the spatial distribution of trees and distributed in the rest of

the area. Earthworms were the most commonly nominated type of soil invertebrate, and were generally regarded as an organism that was beneficial to farm activities.

- Showed that the agropastoral treatments under no-till, as compared with the same treatments under minimum till system, had created soil conditions that are adequate for implementation of the no-till system on the Colombian savanna Oxisols.
- In the long-term crop rotation and ley farming systems experiment (CULTICORE) in the Colombian savannas it was shown that in highly weathered and P-deficient tropical soils, P availability for plant growth may depend more on biologically mediated organic P turnover processes than on the release of adsorbed inorganic P.
- Found that the nitrification inhibition activity of sexual accessions of *B. humidicola* was similar to the commercial apomictic cultivar indicating the possibility for genetic regulation of the trait.
- Showed that the use of bio-char in acid soils of very low natural fertility could increase crop and plant yield and could serve as a valuable tool to increase soil quality of infertile acid soils.
- During the past 2 years, implemented conservation farming practices (minimum tillage, green manures and direct drilling) on an area of about 1000 ha in the Fuquene watershed in Colombia and developed a financial mechanism with National Fund for Financing Farming in Colombia and showed that specific strategic alliances are required for benefiting the poorest farmers with new technologies.

Output target 2006

- ***Impact of three contrasting cropping systems on productivity and nutrient dynamics in hillsides and savannas quantified***

Published work0

D. Diouf, R. Duponnois, A. T. Ba, M. Neyra and D. Lesueur (2005) Symbiosis of *Acacia auriculiformis* and *Acacia mangium* with mycorrhizal fungi and *Bradyrhizobium* spp. improves salt tolerance in greenhouse conditions. Functional Plant Biology 32: 1143-1152
[1]UCAD, Senegal; [2]IRD, Burkina Faso;[1] UCAD Senegal; [3] IRD, Senegal;[4] TSBF-CIAT,Nairobi, Kenya
Abstract: The aim of our work was to assess the growth and mineral nutrition of salt stressed *Acacia auriculiformis* A. Cunn. ex Benth. and *Acacia mangium* Willd. seedlings inoculated with a combination of selected microsymbionts (bradyrhizobia and mycorrhizal fungi). Plants were grown in greenhouse conditions in non-sterile soil, irrigated with a saline nutrient solution (0, 50 and 100 mM NaCl). The inoculation combinations consisted of the *Bradyrhizobium* strain Aust 13c for *A. mangium* and Aust 11c for *A. auriculiformis*, an arbuscular mycorrhizal fungus (*Glomus intraradices*, DAOM 181602) and an ectomycorrhizal fungus (*Pisolithus albus*, strain COI 007). The inoculation treatments were designed to identify the symbionts that might improve the salt tolerance of both *Acacia* species. The main effect of salinity was reduced tree growth in both acacias. However, it appeared that, compared with controls, both rhizobial and mycorrhizal inoculation improved the growth of the salt-stressed plants, while inoculation with the ectomycorrhizal fungus strain appeared to have a small effect on their growth and mineral nutrition levels. Endomycorrhizal inoculation combined with rhizobial inoculation usually gave good results. Analysis of foliar proline accumulation confirmed that dual inoculation gave the trees better tolerance to salt stress and suggested that the use of this dual inoculum might be beneficial for inoculation of both *Acacia* species in soils with moderate salt constraints.

A.O. Esilaba[1], P. Nyende[3], G. Nalukenge[1], J. Byalebeka[2], R.J. Delve[1,3] and H. Ssali[2] (2005) Resource flows and nutrient balances in smallholder farming systems in Mayuge District, Eastern Uganda. Agriculture, Ecosystems and Environment 109: 192-201
[1]CIAT, Kampala, Uganda; [2]Kawanda Agricultural Research Institute, Kampala, Uganda; [3]TSBF-CIAT, Nairobi, Kenya
Abstract: Resource flow models are useful tools that assist farmers in analyzing their soil fertility management strategies and in planning, experimenting and adapting ways to improve the use of scarce local resources. Resource flows and farm nutrient balance studies were carried out in eastern Uganda to ascertain the movement of organic resources and nutrients in and out of the farm system during a participatory learning and action research (PLAR) process. The resource flows were transformed into nutrient flows and partial nutrient balances were calculated using the Resource Kit computer package. Results of a farmers' soil fertility management classification at the start of the PLAR intervention in 1999 revealed that 3% of the farmers were good soil fertility managers (class I), 10% were average soil fertility managers (class II) and 87% were poor soil fertility managers (class III). The results indicate that the net farm nutrient balances in kg ha^{-1} per season for all the nutrients [nitrogen (N), phosphorus (P), and potassium (K)] were negative for both the good and the poor soil fertility managers. Class I farm balances irrespective of the season, were however more negative than those of class III farms. For the long rains seasons (LR 2000, 2001 and 2002), the average net farm nutrient balances for N, P, and K for class I farms were 5.0, 0.6 and 8.0 kg ha^{-1} yr^{-1}, while for the short rains seasons (SR 2000 and 2001), the nutrient balances were 3.5, 0.5 and 6.0 kg ha^{-1} yr^{-1}, respectively. For the class III farms, the average net farm nutrient balances for N, P, and K in the long rain seasons (LR 2000, 2001 and 2002) were 3.3, 0.3 and 4.0 kg ha^{-1} yr^{-1} while for the short rains seasons (SR 2000 and 2001), the nutrient balances were 3.5, 0.5 and 5.0 kg ha^{-1} yr^{-1}, respectively. Soil management interventions for these small-scale farmers should aim at

reversing nutrient depletion with a focus on profitable management of the crop production system, which is the major cause of nutrient depletion.

A.O. Esilaba[1], J.B. Byalebeka[2], R.J. Delve[1,3], J.R. Okalebo[4], D. Ssenyange[5], M. Mbalule[6] and H. Ssali[2] (2005) On-farm testing of integrated nutrient management strategies in Eastern Uganda. Agricultural Systems 86: 144-165.
[1]CIAT, Kampala, Uganda, [2]Kawanda Agricultural Research Institute, Kampala, Uganda, [3]TSBF-CIAT, Nairobi, Kenya, [4]Moi University, Eldoret, Kenya, [5]Africa 2000 Network, Iganga, Uganda, [6]Forestry Resources Research Institute, Kampala, Uganda
Abstract: This paper reports on a Participatory Learning and Action Research (PLAR) process that was initiated in three villages in eastern Uganda in September 1999 to enable small-scale farmers to reverse nutrient depletion of their soils profitably by increasing their capacity to develop, adapt and use integrated natural resource management strategies. The PLAR process was also used to improve the participatory skills and tools of research and extension personnel to support this process. The farming systems of the area were characterized for socio-economic and biophysical conditions that included social organizations, wealth categories, gender, crop, soil, agro forestry and livestock production. Farmers identified soil fertility constraints, their indicators, and causes of soil fertility decline, and suggested strategies to address the problem of soil fertility decline. Soil fertility management diversity among households indicated that most farmers were not carrying out any improved soil fertility management practices, despite previous research and dissemination in the area. Following the diagnosis stage and exposure visits.

A. Mando[1], B. Ouattara[2], M. Sédogo[2], L. Stroosnijder[3], K. Ouattara[2], L. Brussaard[3] and B. Vanlauwe[4] (2005) Long-term effect of tillage and manure application on soil organic fractions and crop performance under Sudano-Sahelian conditions. Soil & Tillage Research 80: 95-101.
[1]IFDC, Togo; [2]INRAB, Burkina Faso; [3]Wageningen University, Netherlands; [4]TSBF-CIAT, Nairobi, Kenya
Abstract: Human-induced degradation of natural resources in general and of soil in particular, is a major problem in many regions, including the Sudano-Sahelian zone. The combined effects of tillage and manure application on Lixisol properties and on crop performance were investigated at Saria, Burkina Faso, to find efficient soil management practices to improve soil fertility. A randomized block design with four treatments (hand hoeing only, hand hoeing + manure, ploughing only, oxen ploughing + manure) in three replications was started in 1990. Ten years later, total soil organic (SOC), particulate organic matter and C mineralization were measured. Initial SOC concentration was 4 mg/g and dropped to 2.1 mg g^{-1} soil in ploughed plots without manure and to 2.5 mg g^{-1} soil in hoed plots without manure. Manure addition mitigated the decrease of SOC in ploughed plots and even built up SOC in hoed plots, where it increased to 5.8 mg g^{-1} soil. Manure had a large effect on the fractions in which SOC was stored. In ploughed plots, a large amount of SOC was stored in physical particles >0.25 mm, while in hand hoed plots the maximum SOC was stored in finer fractions. In the topsoil, hoeing and manure resulted in a higher SOC than ploughing with no manure. However, in the 15–25 cm layer, particularly in September, particulate organic matter was greater in ploughed plots with manure than in hoed plots with manure. Crop yields were highest on ploughed + manure plots and lowest on ploughed plots with no manure. We conclude that applying manure annually mitigates the negative effect of ploughing and hand hoeing on SOC and related properties and therefore can contribute to the sustainability of the agricultural system in the Sudano-Sahelian zone.

A. Sarr, M. Neyra, M. A. Houeibib, I. Ndoye, A. Oihabi and D. Lesueur (2005) Rhizobial populations in soils from natural *Acacia senegal* and *Acacia nilotica* forests in Mauritania and the Senegal River Valley. Microbial Ecology 50:152-162.
[1]University Marrakech, Morocco; [2]IRD, Senegal;[3] FST Nouakchott, Mauritania;[4] UCAD-Senegal; [5]TSBF-CIAT, Nairobi, Kenya

Abstract: Eighty-two strains of rhizobia were isolated from soils taken from several sites in Mauritania and Senegal. These soil samples were collected from natural stands of *Acacia nilotica* and *Acacia senegal*. The soils from Mauritania were less rich in native rhizobia than the soils from Senegal. The strains were characterized using PCR-RFLP and by sequencing the rDNA 16S-23S intergenic spacer region (IGS). They were sorted into 7 IGS groups. These groups were not associated with the geographical origin of the strains or with the host-plant species at the site where the soils were collected. Most of the strains were in three of the IGS groups (I, IV and V). One representative strain from each IGS group was sequenced and showed that the strains were from the genus *Mesorhizobium*. IGS groups I, IV and VI were close to the species *M. plurifarium* (AF345263), IGS groups II and III were close to the species *Mesorhizobium* sp. (AF510360), IGS groups V were close to the species *Mesorhizobium* sp. (AF510366) and VII to *Mesorhizobium* sp. (AF510346).

B. Vanlauwe[1], K. Aihou[2], B.K. Tossah[3], J. Diels[4], N. Sanginga[1] and R. Merckx[5] (2005) *Senna siamea* trees recycle Ca from a Ca-rich subsoil and increase the topsoil pH in agroforestry systems in theWest African derived savanna zone. Plant and Soil 269: 285-296.

[1]TSBF-CIAT ,Nairobi, Kenya, [2]INRAB, Benin, [3]ITRA, Togo, [4]IITA, Nigeria, [5]KULeuven, Belgium

Abstract: The functioning of trees as a safety-net for capturing nutrients leached beyond the reach of crop roots was evaluated by investigating changes in exchangeable cations (Ca, Mg, and K) and pH in a wide range of medium to long term alley cropping trials in the derived savanna of West Africa, compared to no-tree control plots. Topsoil Ca content, effective cation exchange capacity, and pH were substantially higher under *Senna siamea* than under *Leucaena leucocephala*, *Gliricidia sepium*, or the no-tree control plots in sites with a Bt horizon rich in exchangeable Ca. This was shown to be largely related to the recovery of Ca from the subsoil under *Senna* trees. The increase of the Ca content of the topsoil under *Senna* relative to the no-tree control treatment was related to the total amount of dry matter applied since trial establishment. The lack of increase in Ca accumulation under the other species was related to potential recovery of Ca from the topsoil itself and/or substantial Ca leaching. The accumulation of Ca in the topsoil under *Senna* had a marked effect on the topsoil pH, the latter increasing significantly compared with the *Leucaena*, *Gliricidia*, and no-tree control treatments. In conclusion, the current work shows that the functioning of the often hypothesized 'safety-net' of trees in a cropping system depends on (i) the tree species and on (ii) the presence of a subsoil of suitable quality, i.e., clay enriched and with high Ca saturation.

B. Vanlauwe[1], J. Diels[2], N. Sanginga[1] and R. Merckx[3] (2005) Long-term integrated soil fertility management in South-western Nigeria: Crop performance and impact on the soil fertility status. Plant and Soil 273: 337-354.

[1]TSBF-CIAT, Nairobi, Kenya; [2]IITA, Nigeria, Benin; [3]KULeuven, Belgium

Abstract: Crop response, tree biomass production and changes in soil fertility characteristics were monitored in a long-term (1986–2002) alley-cropping trial in Ibadan, Nigeria. The systems included two alley cropping systems with Leucaena leucocephala and Senna siamea on the one hand and a control (no-trees) system on the other hand, all cropped annually with a maize–cowpea rotation. All systems had a plus and minus fertilizer treatment. Over the years, the annual biomass return through tree prunings declined steadily, but more drastically for Leucaena than for Senna. In 2002, the nitrogen contribution from Leucaena residues stabilized at about 200 kg N ha^{-1} yr^{-1}, while the corresponding value for Senna was about 160 kg N ha^{-1} yr^{-1}. On average, the four Leucaena prunings were more equal in biomass as well as in amounts of N, P and cations, while the first Senna pruning was always contributing up to 60% of the annual biomass or nutrient return. Maize crop yields declined steadily in all treatments, but the least so in the Senna + fertilizer treatment where in 2002 still 2.2 Mg ha^{-1} of maize were obtained. Nitrogen fertilizer use efficiency was usually higher in the Senna treatment compared to the control or the Leucaena treatment. Added benefits due to the combined use of fertilizer N and organic matter additions were observed only for the Senna treatment and only in the last 6 years. At all other times, they remained absent or were even negative in the Leucaena treatments for the first 3 years. Most chemical soil fertility

parameters decreased in all the treatments, but less so in the alley cropping systems. The presence of trees had a positive effect on remaining carbon stocks, while they were reduced compared to the 1986 data. Trees had a positive effect on the maintenance of exchangeable cations in the top soil. Exchangeable Ca, Mg and K – and hence ECEC – were only slightly reduced after 16 years of cropping in the tree-based systems, and even increased in the Senna treatments. In the control treatments, values for all these parameters reduced to 50% or less of the original values after 16 years. All the above points to the Senna-based alley system with fertilizers as the more resilient one. This is reflected in all soil fertility parameters, in added benefits due to the combined use of fertilizer nitrogen and organic residue application and in a more stable maize yield over the years, averaging 2.8 Mg ha^{-1} with maximal deviations from the average not exceeding 21%.

E. Barrios[1], J.G. Cobo[1], I.M. Rao[1], R.J. Thomas[1,2], E. Amézquita[1], J.J. Jiménez[1,3],and M.A. Rondón[1] (2005) Fallow management for soil fertility recovery in tropical Andean agroecosystems in Colombia. Agriculture, Ecosystems and Environment 100: 29-42.

[1]TSBF-CIAT, Cali, Colombia; [2] ICARDA Syria; [3]Ohio State University, USA

Abstract: Andean hillsides dominate the landscape of a considerable proportion of Cauca Department in Colombia. The typical cropping cycle in the region includes monocrops or intercrops of maize (*Zea mays* L.), beans (*Phaseolus vulgaris* L.) and/or cassava (*Manihot esculenta* Crantz). Cassava is usually the last crop before local farmers leave plots to natural fallow until soil fertility is recovered and a new cropping phase can be initiated. Previous studies on land use in the Río Cabuyal watershed (6500 ha) show that a considerable proportion of land (about 25-30%) remains under natural fallow every year. The focus of our studies is on systems of accelerated regeneration of soil fertility, or improved fallow systems, as an alternative to the natural regeneration by the native flora. Fallow improvement studies were conducted on plots following cassava cultivation. The potential for soil fertility recovery after 12 and 28 months was evaluated with two fast growing trees, *Calliandra calothyrsus* Meissn (CAL) and *Indigofera constricta* L.(IND), and one shrub, *Tithonia diversifolia* (Hemsl.) Gray (TTH), as slash/mulch fallow systems compared to the natural fallow (NAT). All planted slash/mulch fallow systems produced greater biomass than the natural fallow. Greatest dry biomass (16.4 Mg ha^{-1} yr^{-1}) was produced by TTH. Other planted fallows (CAL and IND) produced about 40% less biomass than TTH and the control (NAT) about 75% less. Nutrient levels in the biomass were especially high for TTH, followed by IND, CAL, and NAT. The impact of fallow management on soil chemical, physical and biological parameters related to residual soil fertility during the cropping phase was evaluated. Soil parameters most affected by slash/mulch fallow systems included soil total N, available N (ammonium and nitrate), exchangeable cations (K, Ca, Mg and Al), amount of P in light fraction, soil bulk density and air permeability, and soil macrofauna diversity. Results from field studies suggest that the *Tithonia* slash/mulch fallow system could be the best option to regenerate soil fertility of degraded volcanic-ash soils of the Andean hillsides.

Completed work

Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe

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

Soil type, historical management and current resource allocation: three dimensions regulating variability of maize yields and nutrient use efficiencies on smallholder farms

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Soil fertility varies strongly between different fields within and between farms as a consequence of inherent and management factors, that have major implications for crop production and nutrient use efficiencies. We conducted experiments for three years (seasons) that assessed maize yields following application of 100 kg N ha^{-1} with different rates of P (0, 30, 50 kg ha^{-1}) from two sources (single super phosphate and cattle manure) on homefields and outfields on a granitic sandy soil and a red clay soil. For three seasons, maize yields on control plots were larger on the homefields than outfields for both soil types. For the different field types yields were larger in the order: homefield clay (1.5-2.1 Mg ha^{-1}) > homefield sand (0.8-1.0 Mg ha^{-1}) ~ outfield clay (0.6-0.8 Mg ha^{-1}) > outfield sand (0.1-0.3 Mg ha^{-1}). The differences in yields are attributed to the fertility status of the fields due to past application of manure. Soil organic matter, available P, and exchangeable bases were higher on the homefields than outfields, due to farmers' preferential allocation of nutrient resources on fields closest to homesteads. Application of mineral N significantly increased maize yields on homefields in the first season: to 3.1 Mg ha^{-1} on the clay soil and 1.5 Mg ha^{-1} on the sandy soil. Effects of N alone were insignificant on the outfields due to other limiting factors. Greatest yields of about 6 Mg ha^{-1} were achieved on the homefield on clay soil with 100 kg N ha^{-1} and 30 P kg ha^{-1} (SSP). Manure gave larger yields (3-4 Mg ha^{-1}) than SSP (2-3 Mg ha^{-1}) on the homefield on sandy soil and outfield on clay soil. Maize did not respond significantly to N, dolomitic lime and P (both manure and SSP) on the depleted outfield on sandy soil in the first and second seasons. Only in the third season of application of manure (> 30 P kg ha^{-1}, about 20 Mg ha^{-1}) was a significant response in grain yields observed. Large amounts of manure are therefore required for several seasons to restore the fertility of depleted outfields on the sandy soils. N recovery efficiencies without P applied were in the order: sand homefield (20%) > clay homefield (16%) > clay homefield (8%) > sand outfield (5%). Application of SSP and manure significantly increased apparent N recovery efficiencies to about 98% and 97% (clay homefield), 40% and 60% (sand homefield and clay outfield) and 12% and 18% (sand outfield). Measurement of grain yields at different rates of N application revealed that about 6 t ha^{-1} can be achieved at high application N rates (up to 120 kg N ha^{-1}) on the homefield on clay soil, with P applied. Maximum yields of about 3 Mg ha^{-1} were attained on the homefield on sandy soil and outfield on clay soil with less than 60 kg N ha^{-1}. Maize responses to N, SSP, manure and dolomitic lime and attainable yields varied strongly on different fields. A three dimensional perspective to soil fertility management encompassing (i) soil type, (ii) past management of fields and (iii) targeted application of mineral fertilizers and manure is imperative for improving nutrient use efficiencies on smallholder farms.

Multiple effects of manure: a key to maintenance of soil fertility and restoration of depleted sandy soils on smallholder farms

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Manure is a key nutrient resource on smallholder farms in the tropics, especially on poorly buffered sandy soils, due to its multiple benefits for soil fertility. Soil chemical parameters on farmers' fields with different histories of cattle manure application on a sandy soil and a clay soil were measured to assess the long-term effects of manure use. Changes in soil properties were assessed following three years of inorganic N fertilizer application, with manure or mineral P, on fields with different initial fertility. Limiting nutrients and the capacity of manure to supply N, P, bases and micronutrients were also tested in greenhouse pot experiments using maize (*Zea mays* L.). The homefields where farmers concentrated manure and fertilizers were more fertile than outfields which received few inputs. The chemical properties on the homefields on sandy and clay soils respectively were: 0.5% and 1.4% C; 0.04% and 0.08% N; 5.1 and 5.6 pH(H_2O); 7.2 and 12.1 mg kg^{-1} available P; 2.2 and 24.2 $cmol_c$ kg^{-1} CEC; 73% and 78% base saturation, and properties for the outfields: 0.3% and 0.7% C; 0.03% and 0.05% N; 4.9 and 5.4 pH(H_2O); 2.4 and 3.9 mg kg^{-1} available P; 1.6 and 22.0 $cmol_c$ kg^{-1} CEC; and 37 and 69% base saturation. Addition of about 17 t ha^{-1} manure in combination with ammonium nitrate (100 kg N ha^{-1}) for three seasons significantly increased soil organic matter by up to 63%, pH by 0.2 units, available P by 8 (mg kg^{-1}) and base saturation by 20% on the outfield on sandy soil. Sole N as ammonium nitrate (100 kg N ha^{-1}) or in combination with SSP led to acidification of the sandy soils, with a decrease of up 0.8 pH units after three seasons. In the greenhouse experiment N and Ca were identified as deficient on the homefield of the sandy soil and N, P, Ca and Zn were deficient on the outfield. No nutrient deficiencies were detected on the homefield on clay soil, whilst P was deficient on the outfield on clay soil. Manure alleviated the deficiencies of Ca and Zn on the sandy soil in the greenhouse. This study highlights the essential role of manure in sustaining and replenishing soil fertility on smallholder farms through its multiple effects. Manure may not supply sufficient N and required by crops, whilst mineral N and P fertilizers alone do not supply other essential nutrients and may acidify the soil. Integrated use of mineral N and P fertilizers and manure is therefore required for sustainable crop production and soil fertility management.

Soil organic carbon dynamics, functions and management in West African agro-ecosystems

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Soil fertility depletion (mainly N, P and carbon) has been described as the single most important constraint to food security in West Africa. Over half of the African population is rural and directly dependent on locally grown crops. Further, 28% of the population is chronically hungry and over half of people are living on less than US$ 1 per day as a result of soil fertility depletion.

Soil organic carbon (SOC) is simultaneously a source and sink for nutrients and plays a vital role in soil fertility maintenance. In most parts of West Africa agro-ecosystems (except the forest zone), the soils are inherently low in SOC. The low SOC content is due to the low shoot and root growth of crops and natural vegetation, the rapid turnover rates of organic material as a result of high soil temperatures and fauna activity particularly termites and the low soil clay content. With kaolinite as the main clay type, the cation exchange capacity of the soils in this region, often less that 1 $cmol_c$ kg^{-1}, depends heavily on the SOC. There is a rapid decline of SOC levels with continuous cultivation. For the sandy soils, average annual losses may be as high as 4.7% whereas with sandy loam soils, losses are lower, with an average of 2%. To maintain food production for a rapidly growing population application of mineral fertilizers and the effective recycling of organic amendments such as crop residues and manures are essential.

Crop residue application as surface mulch can play an important role in the maintenance of SOC levels and productivity through increasing recycling of mineral nutrients, increasing fertilizer use efficiency, and improving soil physical and chemical properties and decreasing soil erosion. However, organic materials available for mulching are scarce due to a low overall production levels of biomass in the region as well as their competitive use as fodder, construction material and cooking fuel. Animal manure has similar role as residue mulching for the maintenance of soil productivity but it will require between 10 and 40 ha of dry season grazing and between 3 and 10 ha of rangeland of wet season grazing to maintain yields on one hectare of cropland. The potential of manure to maintain SOC levels and maintain crop production is thus limited by the number of animals and the size and quality of the rangeland. The potential livestock transfer of nutrients in West Africa is 2.5 kg N and 0.6 kg P per hectare of cropland.

Scarcity of organic matter calls for alternative options to increase its availability for improvement of SOC stock. Firstly, the application of mineral fertilizer is a prerequisite for more crop residues at the farm level and the maintenance of soil organic carbon in West African agro-ecosystems and therefore most research should focus on the improvement of nutrient use efficiency in order to offer to the smallholder farmers cost-effective mineral fertilizer recommendations. Secondly, recent success story on increasing crop production and SOC at the farm level is the use of the dual purpose grain legumes having ability to derive a large proportion of their N from biological N fixation, a low N harvest and substantial production of both grain and biomass. Legume residues can be used for improvement of soil organic carbon through litter fall, or for feeding livestock with the resultant manure being returned to the crop fields.

In the decision support system for organic matter management, recommendations for appropriate use of organic material was made based on their resource quality, expressed as a function of N, polyphenol and lignin content. High quality organic materials release a high proportion of their N quickly. The impact of organic resource quality on SOC is less clear. Low quality organic resources contain substantial amounts of soluble polyphenols and lignins that may affect the longer-term decomposition dynamics and contribute to the build up of SOC. Future research needs to focus more on whether the organic resource quality concept is also useful for predicting different degrees of stabilization of applied organic C in one or more of the organic matter pools.

Differences in rooting strategies of planted fallows in volcanic-ash soils of hillsides

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In the mid-altitude hillsides of the Colombian Andes, agriculture is typically based on fallow/rotation systems in which forest or bush fallow is cleared for cropping with annuals or perennials. One alternative for poor farmers is to manage short-term fallow systems with planted herbaceous or woody legumes ("improved fallows") that replenish soil nutrient stocks faster than plants in natural succession. These short-term planted fallows can restore soil fertility in soils with limited nitrogen (N) and/or phosphorus (P) by enhancing nutrient recycling through the provision of soil organic matter (SOM).

We used a slash/mulch system with spatial design features of an agroforestry planted fallow system but involves pruning where resulting biomass is applied to the same fallow plot. Our objective was to determine whether planted fallow systems under slash and mulch management would perform better than the predominant practice of natural fallow, which allows regeneration of secondary vegetation. In this study we evaluated root growth and distribution differences among planted fallow species (*Indigofera*, *Calliandra*, and *Tithonia*) under 'slash and mulch' management compared with the natural fallow system.

The study was conducted at two farms in Pescador, located in the Andean hillsides of the Cauca Department, southwestern Colombia (2º48' N, 76º33' W) at about 1500 m above sea level. Planted fallow experiments were established at two farm locations on degraded soils previously cultivated with cassava for three years, corresponding to the typical end of cropping cycle when soils are left to natural fallow. The BM1 experiment was established at San Isidro Farm in Pescador as a random complete block (RCB) design with four system treatments and three field replications. Planted fallow system treatments included two tree legumes, *Calliandra calothyrsus* Meissn.(CIAT 20400) (CAL) and *Indigofera constricta* Rydb. (IND) and one shrub *Tithonia diversifolia* (Hems.) Gray (TTH) from the Asteraceae family, compared to a natural fallow system (NAT). Experiment BM2 was established at the Benizio Velazco Farm also in Pescador. It was also established as a RCB design but due to limited space it consisted of three treatments with three field replications. IND and CAL were pruned to 1.5 m height at 18 months after planting and weighed biomass was laid down on the soil surface. In TTH plants were pruned to 20 cm for a total of six times, starting eight months after planting and weighed biomass laid on the soil surface.

Whole plot measurement of biomass production during each pruning event (by plant part) was carried out and a composite sub-sample taken for laboratory analyses before laying down the pruned biomass on the soil surface. All above ground biomass was harvested after 27 months with the conclusion of the fallow phase, weighed, sub sampled and laid on the soil surface. Firewood biomass (stems and large branches) was removed from the field and weighed, while leaving leaves, sexual structures (flowers&pods) and small branches on the soil surface. Whole plot measurements of biomass production in NAT was only conducted once at the end of the fallow period (27 months) when all existing natural re-growth vegetation was slashed and sub-samples for analysis taken prior to applying the biomass on the soil surface.

After 14 months of plant growth, a sample area of 1 m^2 was randomly selected within each plot and all the above ground biomass in this area was harvested. The biomass from the rest of the plot was harvested for the total biomass determination. The biomass from the sample area was separated into leaves, stems and the reproductive structures (flowers and seeds). Root distribution was determined using soil coring method. Soil samples were collected from 12 core samples taken with a 5 cm diameter manual auger into each area used for sampling of shoot biomass. Coarse and fine roots were separated from the soil by washing out the roots on a 1 mm sieve for each soil layer (0-5, 5-10, 10-20 and 20-40 cm). After washing out the roots on a 1 mm sieve, the "live" roots were hand separated from organic material. Root length was measured with the Comair Root Length Scanner and expressed in km of root length per m^2 of ground area. Root biomass was determined after drying the samples in an oven at 70 °C for 2 days. The specific root length was calculated in m of root length per g of dried roots. All statistical analyses were performed using SAS.

Increase in age of the planted fallow plants increased shoot biomass production at both farms of BM1 and BM2 (Table 1). Calliandra was more productive on the less fertile BM2 farm than on the fertile BM1 farm. Indigofera was more productive on the fertile BM1 farm. Calliandra had greater values of leaf area index than the other 2 species of planted fallows at 14 or 27 months after planting. Shoot biomass production of natural fallow at 14 months was similar to that of Calliandra and Tithonia at BM1 farm. At 27 months after establishment, live shoot biomass (leaf + stem) of Indigofera was greater at BM1 farm while Calliandra was greater at BM2 farm. Calliandra also had greater biomass of reproductive structures at 14 months after establishment.

Table 1. Leaf area index and shoot biomass components of three planted fallow species (*Calliandra calothyrsus* CIAT 20400, *Indigofera constricta* and *Tithonia diversifolia*) at two times after establishment compared with natural fallow at 2 farms (BM1 and BM2) in a hillsides agroecosystem of Pescador, Cauca, Colombia.

Fallow species	Age of the plant (months)	Leaf area index ($m^2\ m^{-2}$)	Leaf biomass	Stem biomass	Reproductive structures biomass	Live shoot biomass	Dead shoot biomass	Shoot regrowth	Total shoot biomass
				(Mg ha^{-1})					
BM1									
CAL	14	2.53	4.24	6.12		10.36			10.36
IND	14	1.47	3.07	15.93	0.15	19.07			19.07
TTH	18	6.31	2.76	11.38	0.44	14.58	0.40	6.20	21.18
NAT	18	1.81	1.40	5.50		6.90	3.64		10.54
LSD($P<0.05$)		4.53	2.66	NS	NS	NS			NS
CAL	27	8.78	7.37	15.97		23.34			23.34
IND	27	4.11	2.96	26.38	0.10	29.44			29.44
TTH	27	14.14	5.68	7.12		12.81		26.81	39.62
NAT	27					11.48			11.48
LSD($P<0.05$)		7.60	2.68	11.36					18.10
BM2									
CAL	14	4.24	8.70	13.06	0.44	21.84			21.84
IND	14	0.87	1.95	12.61	0.04	14.58			14.58
NAT	18	0.83	0.63	2.42		3.05	2.37		5.42
LSD($P<0.05$)		1.08	1.64	NS		13.85			14.02
CAL	27	7.65	9.46	28.09		37.55			37.55
IND	27	3.17	2.49	19.22	0.03	21.73			21.73
NAT	27					6.12			6.12
LSD($P<0.05$)		3.70	3.57	NS		15.71			15.71

NS = not significant

Differences among planted fallows in root attributes and root to shoot relationships are shown in Table 2. Greater values of root length and lower values of root biomass indicate the fine root production. Differences among planted fallows in comparison with native fallow in distribution of fine root length across 0 to 40 cm soil depth are shown in Figure 1. Native fallow showed greater fine root production than planted fallows at both farms. Fine root production (fine root length) of planted fallows increased with the age of the plants in the fertile farm of BM1 but not on infertile farm BM2 (Figure 1). Coarse root length of Calliandra was also greater than that of Indigofera on the infertile BM2 farm. Corase root biomass values were markedly superior for Calliandra compared to other fallow species at both farms. As expected, the lowest values of coarse roots were observed with native fallow at both farms. Native fallow also showed markedly greater values of root length to shoot biomass than the planted fallows. Values of root biomass to shoot biomass ratio were also greater for Calliandra, particularly at the infertile BM2 site. This indicates the ability of Calliandra to adapt to infertile soil conditions by changing partitioning of biomass to root growth and development over time. The ability to produce greater amounts of fine roots by Calliandra, particularly at deeper soil layers (Figure 1) is an adaptive strategy to explore greater volume of soil for immobile nutrients such as P that is low in its availability in these volcanic-ash soils of Andean hillsides.

Table 2. Root length, root biomass and root to shoot relationships of three planted fallow species (*Calliandra calothyrsus* CIAT 20400, *Indigofera constricta* and *Tithonia diversifolia*) at two times after establishment compared with natural fallow at 2 farms (BM1 and BM2) in a hillsides agroecosystem of Pescador, Cauca, Colombia.

Fallow species	**Age of the plant (months)**	**Root length** ------------km m^{-2}--------			**Root biomass** -------------kg ha^{-1}------------			**Root length to shoot biomass ($m\ g^{-1}$)**	**Root biomass to shoot biomass ($g\ g^{-1}$)**
		Fine	**Coarse**	**Total**	**Fine**	**Coarse**	**Total**		
BM1									
CAL	14	2.20	0.07	2.26	517	1838	2355	2.41	0.26
IND	14	1.85	0.09	1.95	303	2554	2857	1.17	0.20
TTH	18	3.08	0.00	3.08	308	114	421	3.47	0.04
NAT	18	5.65	0.00	5.65	491	25	516	5.96	0.06
LSD($P<0.05$)		2.06	0.07	2.06	NS	NS	NS	3.61	NS
CAL	27	6.38	0.08	6.45	574	6275	6849	3.88	0.38
IND	27	5.49	0.03	5.52	428	1957	2386	2.09	0.09
TTH	27	4.19	0.01	4.21	199	521	721	1.95	0.04
NAT	27	11.38	0.02	11.40	1566	139	1705	9.05	0.14
LSD($P<0.05$)		NS	0.05	9.59	3947	3631	5586	5.59	0.27
BM2									
CAL	14	5.88	0.15	6.02	778	3972	4750	2.94	0.23
IND	14	4.50	0.05	4.55	600	535	1135	5.29	0.13
NAT	18	8.45	0.00	8.46	465	154	619	16.54	0.12
LSD($P<0.05$)		NS	0.10	NS	267	1554	1697	8.71	NS
CAL	27	6.20	0.13	6.34	497	15711	16208	1.93	0.49
IND	27	4.16	0.04	4.20	346	1162	1507	2.08	0.07
NAT	27	6.13	0.01	6.14	463	278	741	11.15	0.14
LSD($P<0.05$)		NS	0.10	NS	NS	8431	8757	2.66	0.32

NS = not significant

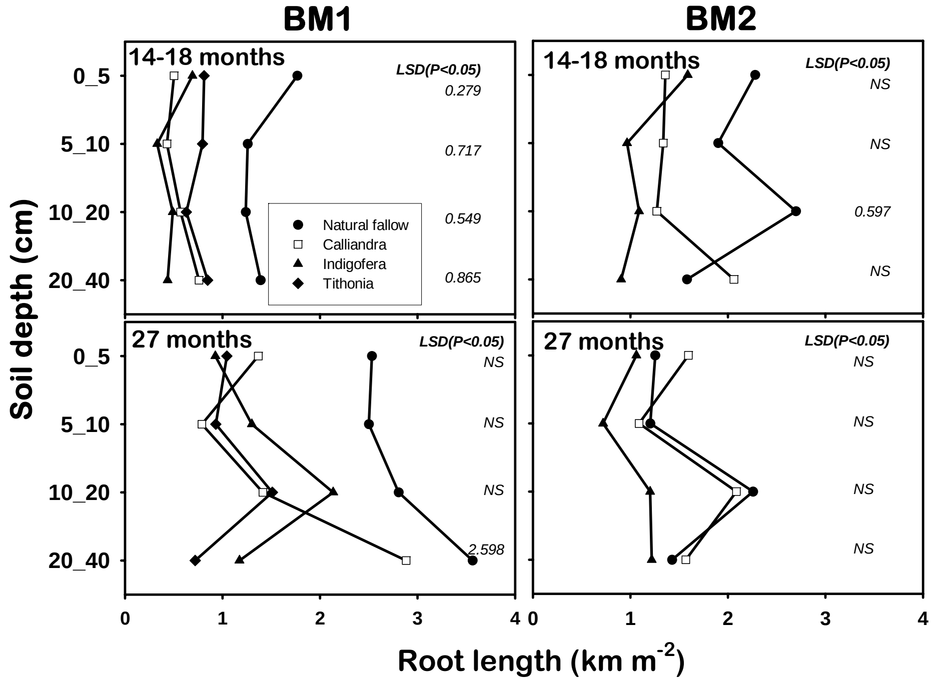

Figure 1. Distribution across soil depth (0-40 cm) of length of the fine roots of three planted fallow species (*Calliandra calothyrsus* CIAT 20400, *Indigofera constricta* and *Tithonia diversifolia*) at two times after establishment compared with natural fallow at 2 farms (BM1 and BM2) in a hillsides agroecosystem of Pescador, Cauca, Colombia.

Work in progress

Biophysical characterization of the Quesungual Agroforestry System

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The Quesungual agroforestry system (QSMAS) is an alternative to slash and burn management. It is based on planting annual crops (maize, sorghum, beans) and pastures under an indigenous slash and mulch management system. It combines the regrowth of native forest vegetation with no burning and zero tillage/direct planting operations on a permanent soil cover. More than 6,000 farmers covering an estimated area of 7,000 ha, who have adopted the QSMAS system during the last ten years in Honduras, have increased crop yields by more than 100% (maize from 1200 to 2500 kg ha^{-1}, beans from 325 to 800 kg ha^{-1}) in comparison with the traditional slash and burn system. More innovative farmers are intensifying and diversifying this system using vegetables and market-oriented cash crops as well as livestock.

In 2004, we obtained financial support from the Water and Food Challenge Program in order to determine the key management principles behind the social acceptance and biophysical resilience of QSMAS and its capacity to sustain crop production and alleviate water deficits on steeper slopes with high risk of soil erosion. One of the specific products of the project is the socio-economic and biophysical characterization of the system

The characterization study included the analysis of land cover, elevation and slope based on 1: 20,000 Digital Elevation Model (DEM) developed for the Southern Lempira region. This model was generated by combining topographic digital maps and Landsat Images from 2002. Rainfall data was obtained from the service of Meteorology of Honduras. The study was complemented with field visits to verify accuracy of de DEM.

Preliminary analysis of the information indicates that the management principles of the Quesungual (no burning, permanent cover of the soil and management of trees) are practiced over an area of 59,475 hectares (Figure 2). Seventy percent of this area lies within a range of 200- 800 masl and has slopes greater than 50%. The overall landscape is characterized by a mosaic of maize-based systems inserted within large areas of fallows after Quersungual. Mean annual rainfall varies from 1925 to 2218 mm depending on altitude. Most of the rain falls between the period May- November. The driest and hottest months are February and April, respectively while the wettest months are between June to September. Mean annual temperature varies between 16-21^0 C (minimum) and 28-34 ^{0} C (maximum).

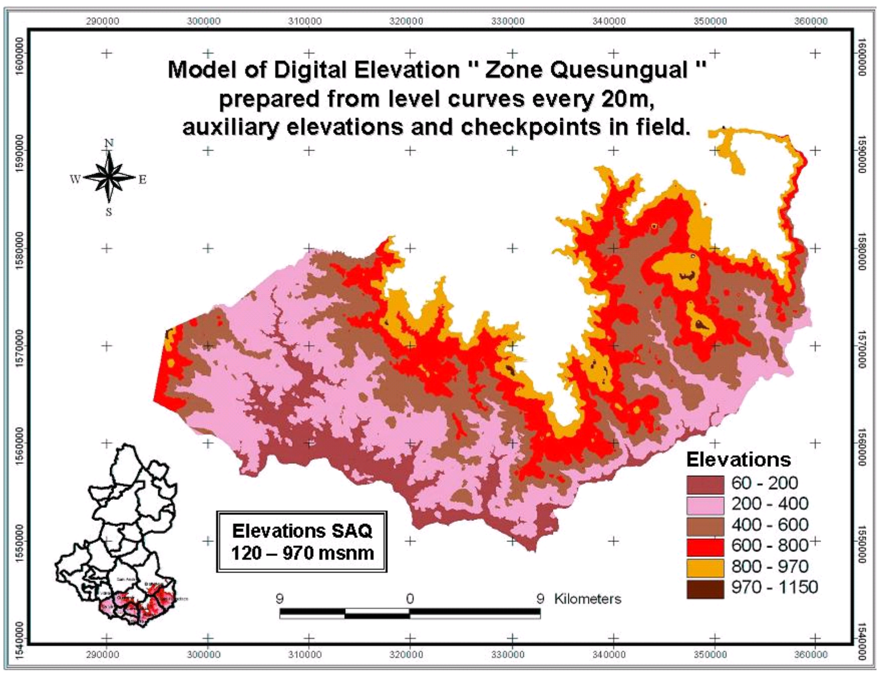

Figure 2. Map of the area of influence of the Quesungual system in the southern region of Lempira, Honduras using a digital elevation model.

The study examined how soil properties varied along several toposequences that included the on-farm plots used for the project with respect to modal profiles of two watersheds containing the on-farm plots (Figure 3). In the first phase of the study, the main soil units found at the watershed scale were identified using aerial photographs, secondary information and photo- interpretation. This information was verified and corrected in the field in a second phase of the work. Modal soil profiles were then described for each soil unit and samples were taken to the lab for analysis.

Main results indicate that the geology of the area is characterized by a massive presence of intrusive material developed during the tertiary. This material is comprised of fragmented rocks of diorites and grain-diorites of varying sizes underlying close to the soil surface in the upper part of the watersheds. Soil depth varies between 12 - 100 cm but most common depth is less than 40 cm. Dominant soil textures are sandy to clay loams and slopes are greater than 50%. Most common soil orders found along the toposequences were Entisols (upper parts), Inceptisols (medium parts) and Mollisols (lower parts).

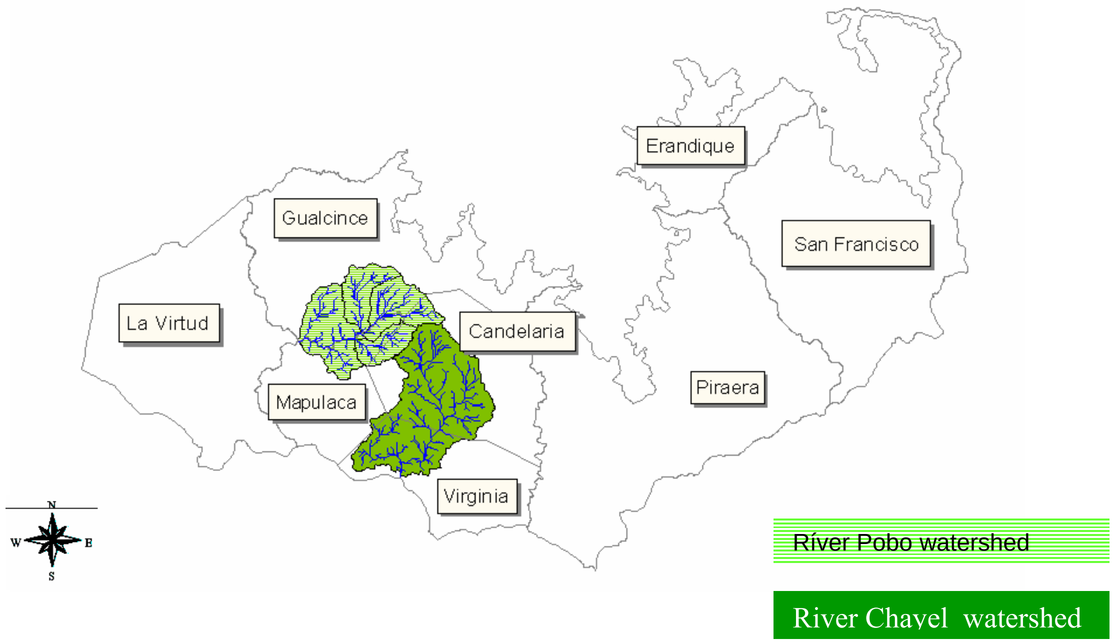

Figure 3. Location of the study area for the detailed soil characterization at toposequence and watershed levels.

Soil analyses are presented in Table 3. Results indicate that soil properties at the farm and watershed scales are similar. On the other hand they show clearly that these soils are acid and very deficient in P.

Table 3. Comparison between topsoil chemical properties of on-farm toposequences and the modal profiles of the watersheds Chayel and Pobo.

Soil Properties	**Sampling scale**			
	Farms (28 topsoil samples)		**Watershed (25 topsoil samples)**	
	Range	Mean	Range	Mean
pH	4.6- 6.2	5.0	5.0-6.4	5.5
SOM (%)	1.4-8.9	3.7	1.07-5.70	3.7
Total N (%)	0.1-0.4	0.2	0.05-0.29	0.2
P (ppm) Olsen	0.5-9.0	2.6	0.5-9.0	2.4
Ca (ppm)	420-4040	2612	320-3930	1709
K (ppm)	45-360	156	40-325	157
Mg (ppm)	51-557	406	16-1500	387
Zn (ppm)	0.3-2.2	0.7	0.26-0.42	0.3
Cu (ppm)	0.02-1.20	0.42	0.2-1.46	0.6
Fe (ppm)	4.0-58.0	27.4	10-90	29.3
Mn (ppm)	1.0-27.0	10.7	1.0-16.0	6.1

Response of maize-bean rotation to different rates of phosphorus fertilizer and chicken manure to a Colombian volcanic-ash soil

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High P fixation is common in soils with high volcanic ashes, and the crop response by farmers is generally sub-optimal in this kind of soils under continuous cultivation. To maximize P fertilizer use efficiency under these conditions, both from organic and inorganic amendments, it is necessary to be able to quantify the residual value of previous P fertilizer applications. To investigate this further, two experiments on Colombian volcanic ash-soils were designed: 1) RPRE, using triple super phosphate applied once only at the beginning of the experiment, or annually to the maize crop in a two-crops-per-year rotation; and 2) CHME, using chicken manure applied annually to the maize crop in the same two-crops-per-year rotation. The objectives of these experiments were: 1) to determine optimal levels of soluble phosphate fertilizer/chicken manure for maize and common bean on these soils; 2) to characterize the fate of P fertilizer and chicken manure applications (uptake by crop, removal in products, immobilization in organic matter, reversion to less soluble inorganic phases); 3) to determine the residual value of phosphate applications (only for RPRE experiment); and 4) generate data for future parameterization of simulation models - e.g. APSIM. In this paper we show the response of crops on plant biomass production and grain yield.

The experimental plots were located in Pescador, Cauca department, Colombia (2º48' N, 76º33' W, 1500 m.a.s.l.). Soils are derived from volcanic-ashes, presenting an allophone content of 14.5%, and have been classified previously as Andepts (Oxic Dystropepts); however, since 1999 Andepts are considered as Andisols. Figure 4 shows the climate conditions during experimental time. Both experiments were randomised complete block designs with four replicates. Plot size in both experiments was 7 m by 7 m. RPRE included nine treatments, corresponding to 9 levels of P fertilizer as triple super phosphate applied once only at the beginning of the experiment (20, 40, 80 and 160 kg P ha^{-1}) or annually (0, 5, 10, 20 and 40 kg P ha^{-1}) to the maize crop in a two-crops-per-year rotation. CHME included 4 treatments, corresponding to 4 levels of chicken manure (0, 3, 6 and 12 Mg ha^{-1}) applied annually to the maize crop in the same two-crops-per-year rotation. However, in the last maize cycle, the 5 kg P ha^{-1} treatment in RPRE was increased to 160 kg P ha^{-1} to compare with the residual treatment of 160 kg P ha^{-1}. Similarly, chicken manure was not applied in the 12 Mg ha^{-1} treatment of CHME for assessing residual effect. Fertilizer and manure were applied to soil by broadcasting.

Maize cv. Cresemillas, with a density of 50,000 plants ha^{-1}, was planted in September 2001 and dry bean cv. ICA Caucayá (PVA 773), with a density of 166,666 plants ha^{-1}, was planted in next March. This maize and bean rotation was continued through three more cycles using the same scheme (Figure 1). Basal nutrients (N, K, Ca, Mg, and micronutrients) were applied to both crops and to all treatments in RPRE but not in CHME. Maize was harvested between February-March of 2002 till 2005, while beans were harvested between June-July of 2002 till 2005 (Figure 4). In each harvest, crop plant parts and weeds were separately weighed and sampled for laboratory analysis (data not shown). Maize and bean yields were expressed as grain weight (means±stderr) at 12.5% and 14% of water content, respectively.

In general, maize and bean biomass and yields in both RPRE and CHME responded proportionally to the gradual applications of P. In RPRE at the first cycle, for example, the control (0) and 160R had the lowest and greatest values, respectively (Figure 5). The same was observed in CHME, where control (0M) obtained the lowest values while 12M obtained the greatest. These results confirmed the hypothesis that these soils, by it self, can not sustain crop production due to their low P availability and high P fixation, and therefore high or continuous P additions (combined with adapted cultivars to low-P conditions) should be employed.

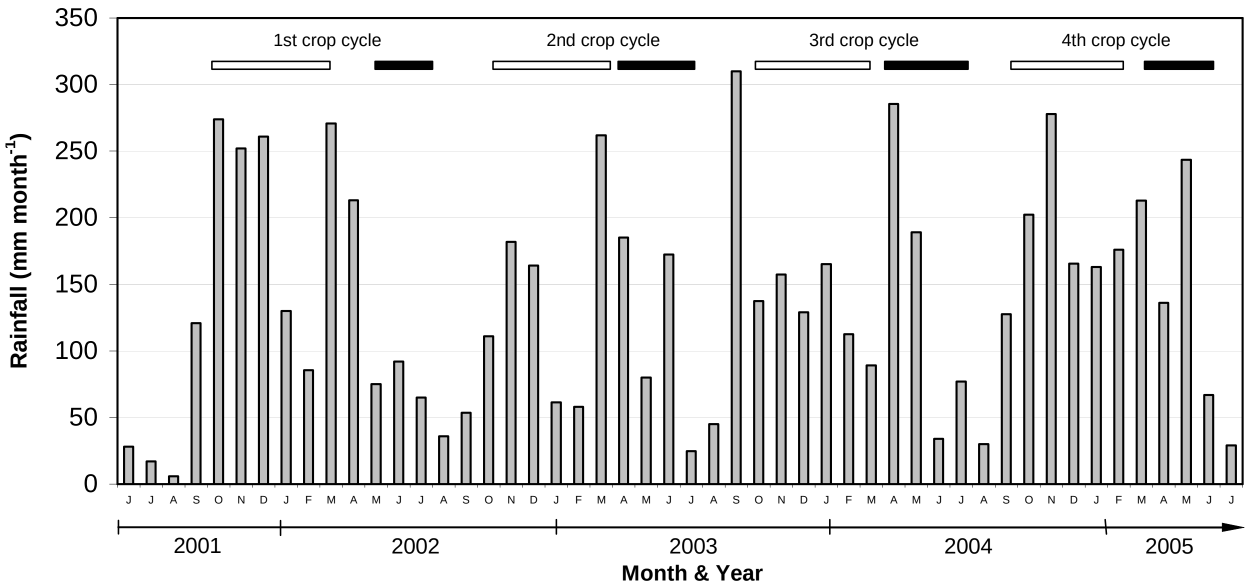

Figure 4. Monthly rainfall (shadow area) in Pescador (Cauca, Colombia) during experimental time. Horizontal bars refer to cropping cycles (□ maize ■ beans).

Maize biomass and yields in the 2nd cycle were generally the lowest among all cycles, especially in RPRE. Since diseases and insects were not a major problem in different seasons of maize, this was attributed to inadequate rainfall. In fact, there was a very low rainfall (~ 60 mm/month) in January-February 2003, which coincided with the stages of flowering and grain filling, respectively (see Figure 4). Diseases (e.g. Anthracnose and Mustia), on the contrary, did affect severely beans, mainly in RPRE in the 2nd and 3rd cycles (Figure 5). Actually, either the crop totally failed or produced insignificant yields in most of the treatments (only 40A and 160R had some production). Apparently, greater P availability due to greater P applications induced bean plants to recover from diseases (more quickly or more effectively) and therefore they could yield at a greater level.

As expected, crop biomass and yield diminished in residual P treatments of RPRE after the first cropping cycle, and this decrease, in general, was conversely proportional to the level of fertilization (as higher the P applications as lower the decrease in crop production). This sharp decrease was presumably due to a high soil P-absorption and/or P loses. From all annual applications of SFT in RPRE only 40A increased biomass and yield with time. In fact, in the 4th cycle, crop response from residual 160 kg P ha^{-1} was lower than the accumulative applications of 40 kg P ha^{-1} (x 4 years). This suggests that ≥ 40 kg P ha^{-1} $year^{-1}$ could gradually build-up soil available P in opposition to P fixation and P loses; and this practice is recommended against only one large amount of P application at the beginning of the cycle.

Maize yields for P80R and P160R were similar to those obtained with the high inputs of chicken manure (i.e. 12 t ha^{-1}), especially in the first cropping cycle. However, lower yields in RPRE in the following cycles confirmed that application rates were inadequate to get similar yields to those in CHME or there was some other limiting factor that was being corrected by chicken manure additions (e.g., improved soil moisture). From CHME we also could argue that despite relatively greater response of crop yields to 12 Mg chicken manure ha^{-1} (especially for beans), the current practice by farmers (3-6 Mg ha^{-1}) seemed to be a reasonable trade-off between satisfactory yields with low cost of inputs (i.e. manure) versus greater yields with greater input costs involved.

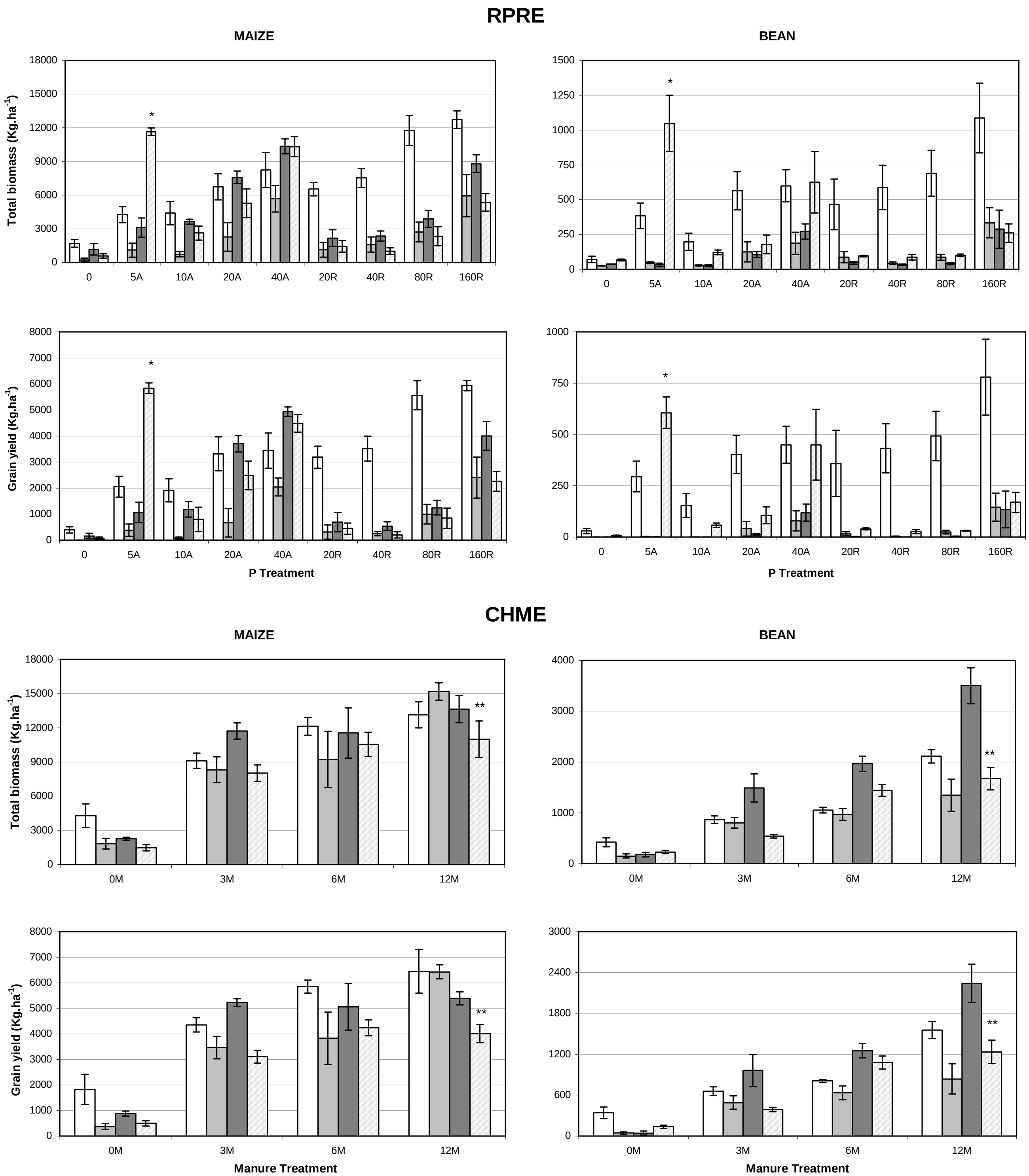

Figure 5. Total biomass and grain yield for maize and bean crops in RPRE and CHME during four years of experimentation. Vertical bars refer to standard errors of the mean (* application of 160 kg P ha^{-1}; ** chicken manure was not applied anymore).

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

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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 P 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.

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 m.a.s.l.). The area has a mean temperature of 19.3◦C 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 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.

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.

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 Soil P module.

The chicken manure (CM) used each year in the experiment had been analysed 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.

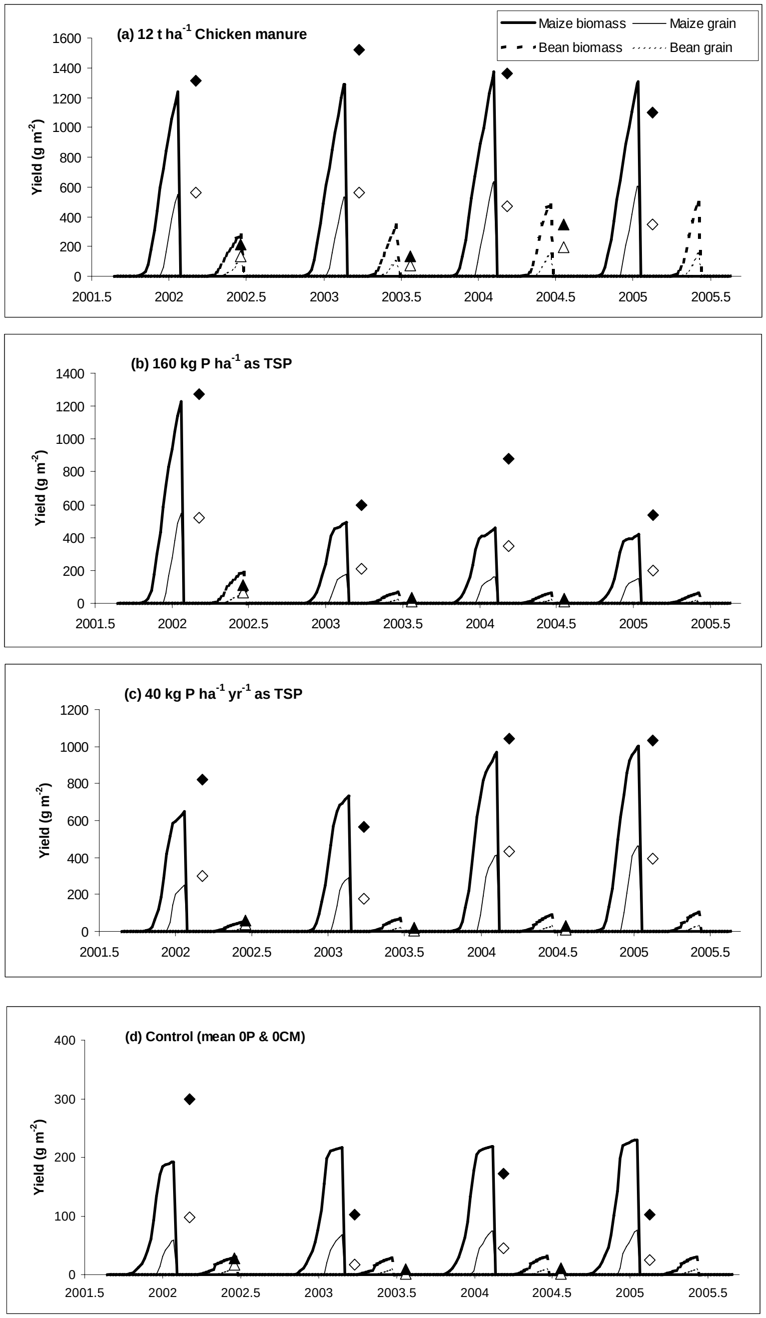

Figure 6. Comparison of observed (symbols) and predicted (lines) for total biomass and grain yield of maize and bean crops (2001-2005) for selected treatments. Note that the vertical scales differ for different treatments.

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. Based on published data on P sorption in soils similar to the experimental site, 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. The values used are included in Table 1. 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°C) was increased from 0.5 to 0.8 to improve the fit of the model to the observed data.

Figure 6a shows a comparison of the observed and predicted crop yield through the eight seasons for selected treatments. For the 12CM treatment (Figure 1a) 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 (Figure 6d) 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. In Figure 1d the observed data are the means of these two treatments. The other two treatments compare the effects of the one-time application of 160 kg P ha^{-1} as TSP (Figure 6b) with the annual input of 40 kg P ha^{-1} (Figure 6c). 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.

Conclusion: 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.

Developing high fertility trenches technology for high value crops in hillsides

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The hillsides agroecosystem in tropical America includes an area of 96 million hectares. Of this area around 25 million hectares are highly degraded and 53 million are under a rapid process of degradation. Colombian Andean region shows soil erosion problems from very light to severe. In Colombia the hillsides agroecosystem is characterized by the presence of coffee, plantains, pastures/grasses and annual crops (maize, beans, cassava, etc.). In this agroecosystem population pressure has lead to deforestation allowing new areas to enter into cultivation in steep slopes that are prone to erosion. It is anticipated that in 10 to 20 years time there will be water shortage in many towns of the Andean zone, therefore, it is necessary from now on, to take the measures to avoid it.

As part of an ongoing collaborative project between the CRC (Regional Corporation of Cauca) and TSBF-LAC, in several of the areas of influence of the project, farmers identified the need to intensify production systems in their farms through the use of high value crops (typically, vegetables and some short cycle fruits). One of the high priorities identified by farmers was the use of soil management methodologies to improve soil quality at farm level in strips where these vegetables could be grown with minimum edaphic limitations. Previous work conducted at San Isidro, Pescador, in the region, showed the feasibility of using high fertility trenches to maximize the effect of modest inputs (fertilizers, animal manures, green manures etc) that farmers could afford to increase yields. Many farmers in the region have taken the concept tested on station, and are now using the approach in their farms with their own adaptation and improvements, using the inputs to which they have more access in each location. The farmers involved in the project with CRC have requested this methodology to be included as part of the activities proposed to increase profitability of their production systems. CRC has requested to include and test the performance of high fertility trenches in several farms along the Cauca department. Preliminary data are being generated and will be reported next year.

Currently, small farmers are preparing the whole area of a piece of land for cultivation, leaving a bare soil subjected to active forces that cause erosion. Besides, farmers are practicing agriculture with limited economic resources. To establish economically viable and sustainable production systems, it is required an atmosphere of favorable policies and efficient use of resources. To face the problems of soil's fragility and to combat the problems of low productivity and degradation, strategies integrating genetic resources, technologies for soil and water conservation, use of fertilizers and biological control of insects and diseases, must be planned in a rational manner to improve livelihoods of farmers and to conserve natural resources. To restore degraded and abandoned soils, the development of high fertility contour trenches technology with the following objectives is proposed: a) regain use of abandoned lands, b) increase water infiltration and control soil erosion, c) improve soil fertility, and d) introduce high value crops. The main objective of the study is to increase productivity of Andean hillside soils through the management of systems that allow increasing their productive capacity and simultaneously are able to control soil losses, improve water supply to crops, and protect the environment while improving the quality of life of the farmers. The following are the specific objectives:

- Improve economical condition of farmers by conserving and improving soils and water resources avoiding degradation of productive soils and environment.
- Introduce the use of "high fertility trenches" as a way to avoid erosion and runoff production, to regain the use of abandoned lands and to improve soil productivity.
- To produce high value crops: vegetables, flowers, fruits, etc. for farmer's better economical conditions.
- To characterize and to evaluate plants (grasses, legumes, etc.) that can serve as soil cover crops and enhancers of soil quality.
- To transmit to technicians and farmers new methodologies to improve and conserve soils and water to produce high value crops.

The following methods were used:

- Choose in a farm (in agreement with the farmer) a degraded or low productivity area.
- Determine the degree of slope (for distances between trenches).
- With the help of a level, mark out a level curve in the middle of the plot and then parallels to countering the selected area.
- In each contour curve dig a trench of 30 cm wide and 25 to 30 cm depth through the length of the field.
- According to soil chemical analysis, add a mixture of lime, chicken manure and fertilizers to improve soil fertility.
- After a week, sow a high valuable crop (vegetables, flowers, fruits, etc.).
- If possible install a drip irrigation system.
- The land area between trenches will remain in its original state of vegetation to protect the soil against the impact of drops of rainfall.
- See Figure 7 for details on methodology.

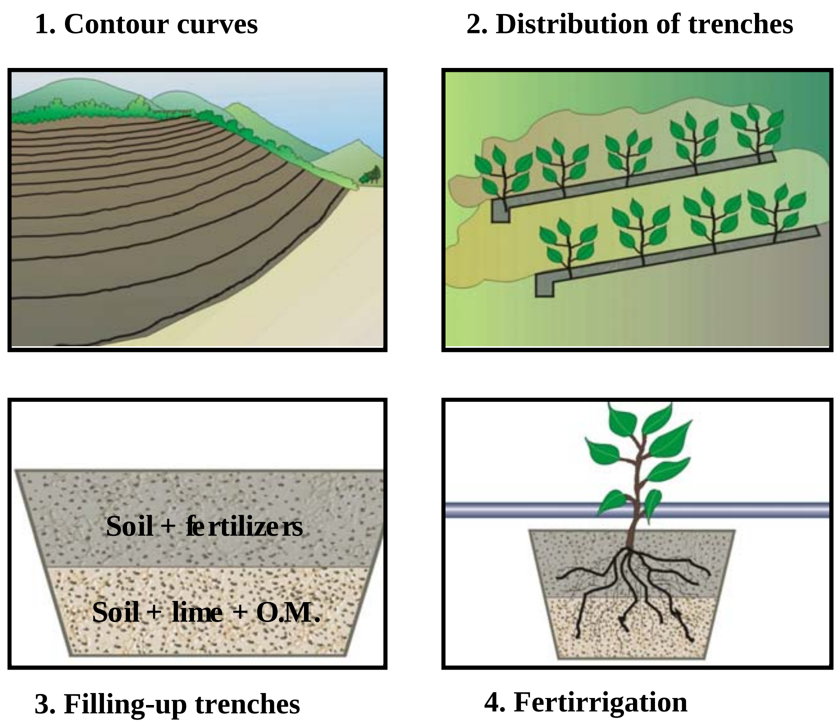

Figure 7. Trenches of high fertility used for cultivating commercial crops in degraded soils of Pescador – Cauca, Colombia.

Production cost and benefits of establishing one hectare of pepper in high fertility trenches: Table 4 presents the results obtained inone experiment located in hillsides of the Andes, San Isidro, Pescador, Department of Cauca (1500 masl, 1900 mm of precipitation and 19°C as average temperature) using pepper as testing crop. Data obtained in experimental plots are expressed in terms of one hectare.

Table 4. Production costs and economic benefits of pepper *(Capsicum anuum)* cultivation using high fertility trenches technology.

Description	Unit	Amount	Unit value US$	Total value US$
Activities				
Seedling	Wages	1.96	5.60	10.97
Ditches	Wages	12.32	5.60	68.99
Sowing	Wages	3.36	5.60	18.82
Weeding	Wages	7.84	5.60	43.90
Controls	Wages	3.64	5.60	20.38
Fertilizers	Wages	3.36	5.60	18.82
Irrigation	Wages	10	5.60	56.0
Harvesting	Wages	13.44	5.60	75.30
Subtotal				**313.18**

Materials				
Seed	kg	0.1	31.31	3.13
Insecticides	Liter	1.12	26.31	29.46
Fungicides	kg	1.96	17.54	34.38
Chicken manure	Mg	0.84	49.34	41.44
Calfos	50kg	4.48	5.26	23.56
15-15-15	50kg	1.4	37.72	52.80
MgO	50kg	0.28	20.61	5.77
Agrimins	50kg	0.28	24.56	6.87
Boxes	Box	267	0.57	152.20
Subtotal				**349.61**
Total expenses				**662.79**
Yields	Mg	4		
Price of sale	kg		0.35	
Profits				**737.21**

1 USD: $ 2280 Colombian pesos

Economical analysis shows that using this technology farmer could expect to have benefits of US$737 per hectare per cycle (4 months). However, small farmers can't afford to sow one hectare but small areas (50-1000 m^2). Therefore, the benefits are reduced. On the other hand they can also plant 2.0 to 2.65 crops per year. During the second and following years the income could be increased because they do not need to build the trenches.

Effect of disk harrowing intensity on soil sealing in a savanna oxisol of the Eastern plains of Colombia

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The main objective of this study is to evaluate the cumulative effect of disk harrowing intensity on the formation of surface sealing of an Oxisol (Typic Haplusdox isohyperthermic kaolinitic) of the eastern plains of Colombia, through physical characteristics such as structural stability, infiltration, sorptivity, run-off and soil losses. The main hypothesis is that the intensity of harrowing, represented by the cumulative number of disc passes, favors the formation of surface sealing in soils. Sealing and crusting is the natural reaction of the soil to the physical impact of the raindrops falling with high energy on the naked soil. Excessive farming exposes the soil to the impact of the raindrops which destroys the aggregates dispersing them into microaggregates and individual particles that later on are deposited on the surface of the soil, forming the seal that reduces water infiltration, soil aeration and increases run-off. Sealing diminishes considerably the entrance (acceptance) of water into the soil, and therefore the amount of available water to the crops. All this is associated with low structural stability, fine sands and low contents of soil organic matter.

The investigation was carried out in a farm located in Matazul, 40 km East of Puerto López (Meta), at 4° 5' N and 72° 58" W, 160 m.a.s.l, mean annual rainfall is 2,251 mm, average annual temperature 26°C, the soil is classified as an Oxisol (Typic Haplustox Isohyperthermic kaolinitic), extremely acid (pH 4.5-5.0), with low availability of total bases (0.3 $cmol_c$ kg^{-1}), low content of P (2.6 mg kg^{-1}), high aluminum saturation, and low percentage of organic matter (3.5%) at 0-15 cm depth. Soil samples in 15 × 54 m plots were taken, at a depth of 1 cm, following a zigzag course in every treatment. The sampling was carried out 25 days after the harvest of corn; sampling points in every plot were geo-referenced, as well as the extreme points delimiting the plot, to facilitate its location in a map. By the time of sampling experimental plots had accumulated 16, 32 and 64 disk harrow passes in a maize crop; 2, 4 and 8 disk harrow passes under pastures with *Brachiaria dictyoneura;* to be compared with ecosystems of native savanna and gallery forest as controls.

Under field conditions, penetrability was measured using a penetrometer for crusts, soil strength was determined with a torquemeter special for crusts, which allows to measure soil strength up to 1 cm depth in kPa. Infiltration was determined using concentric rings. Results were adjusted to Kostiakov mathematical model to determine the basic infiltration and explain the dynamics of the cumulated water, as well as the infiltration rate and the sorptivity of the soil. Three measurements per trial plot were carried out. Infiltration readings were taken during two hours. Field moisture content, saturated hydraulic conductivity, moisture characteristics, bulk density, pore size distribution, air permeability, aggregate stability, soil texture and true density were evaluated in the laboratory.

For data analysis, the statistical package SAS, version 6.12, was used. A variance analysis (ANOVA) was carried out, to determine the effect of harrow passes on the formation of the seal and the effect on the physical and chemical properties of the soil, using the Duncan test of averages comparison to a level of $P<0.05$. A multivariate analysis of the data allowed establishing interrelations between the physical/chemical properties of the soil and the management systems.

The mean resistance values of penetrability and soil strength reported in Table 5 shows the effect of the use and management of the soil on its capacity to permit normal root development of crops. At the level of soil use, it is observed that the forest treatment reported lower mean values, while the highest values were in the treatments with grasses; the mean values were above the critical value (30 kgf cm-^{2}), which is considered restrictive for the development of roots. The effect of the number of disk harrow passes in grasses and maize presented a direct proportional relationship with soil strength.

Table 5. Values of penetrability and soil strength at 0-1 cm depth in treatments.

Treatment	Penetrability (kgf/^{cm2})	Soil strength (kPa)
Maize 2 passes	33.30	1.86 e
Maize 4 passes	10.58	7.09 e
Maize 8 passes	13.10	25.67 d
Pastures 2 passes	48.48	58.11 c
Pastures 4 passes	100.00	80.67 b
Pastures 8 passes	264.42	95.33 a
Native Savanna	13.85	67.67 c
Forest	0.25	0.61 e
LSD	-----	10.4
CV	-----	14.2
Pr >F	N.S	<0.0001

Means with the same letters in the same column don't present significant differences (P <0.05) for the Duncan Test.

Forest and maize 2-passes treatments showed the highest values in cumulated and rate of infiltration in 2 hours. Sorptivity presented a similar trend in forest and maize 2-passes with higher values of slope, in comparison with the other treatments. Table 6 shows the distribution of dry aggregates in two groups; (aggregates bigger and smaller than 2 mm). A prevalence of big aggregates in the grasses and native savanna treatments is observed, opposite to the maize treatments (with prevalence of small aggregates); the forest treatment presented a balanced distribution of aggregates. The effect of the quantity of harrow passes on the destruction of aggregates (bigger than 2mm) was more evident in the maize treatment; doubling the passes, approximately 50% of the big aggregates were destroyed; this action increases bulk density due to the repacking of the small.

The mean weight diameter (MWD) for dry aggregate size distribution presented highly significant differences between treatments. This demonstrated that the intensity of harrowing decreased significantly the MWD of the aggregates in maize and corroborated the role that pastures have as builders of big aggregates. The MWD shows that the quantity of disk harrowing passes influenced negatively the stability of the aggregates, contrary to the effect of the pasture roots that exerted a beneficial role in the structure and the stability of the soil, tying the aggregates and particles that form and maintain the structure.

Table 6. Mean weight diameter (mm) for aggregate distribution and stability in the different treatments.

Treatment	**%percentage of aggregates**		**Mean Weight Diameter**	
	> 2 mm	**< 2 mm**	**Distribution**	**Stability**
Maize 2 passes	56.01	43.99	3.23 c	1.13 c
Maize 4 passes	29.74	70.26	1.76 e	1.13 c
Maize 8 passes	19.87	80.13	1.23 f	1.00 c
Pastures 2 passes	84.72	15.28	5.10 a	5.56 a
Pastures 4 passes	82.80	17.20	5.03 a	5.93 a
Pastures 8 passes	79.80	20.20	4.86ba	5.73 a
Native savanna	79.33	20.67	4.76 b	4.60 b
Forest	44.16	55.84	2.50d	5.56 a
LSD	___	___	0.25	0.39
CV	___	___	4.06	5.85
Pr >F	NS	NS	<0.001	<0.001

Means with same letters in the same column don't present significant differences (P <0.05) for the Duncan Test.

Results in Table 7 shows the effect of a simulated rain (100 mm h^{-1}) on water infiltration, runoff and eroded sediments in each treatment. Maize treatments showed less cumulative infiltration values than pastures of forest. As the number of harrowing passes increased, more runoff and amount soil eroded was found. It is associated with soil sealing that impedes infiltration and increase run-off. Runoff under maize 8 passes was almost three times greater than that of maize 2 passes. Native savanna produced 11 mm of runoff indicating that under natural conditions the loss of water is high, almost 40% of the rainfall applied. It is important to note that these soils are dominated by fine to very fine sands and have low values of O.M. (>4.0%).

The results obtained indicate that the practices to be applied for improving soil physical conditions of these soils should be focused on increasing water infiltration and stabilizing soil structure, through a good combination of constructive tillage to promote root growth and to the use of mulch and soil covers to avoid the direct impact of rainfall on bare soil.

Table 7. Evaluation of the infiltration layer, run-off and eroded sediments using the mini-simulator of rains (100 mm/h intensity in 30 minutes).

Treatments	Accumulated applied layer (mm)	Accumulated infiltrated layer (mm)	Accumulated run-off layer (mm)	Accumulated eroded soil (g m^{-2})
Maize 2 passes	55.90	49.10	6.80	8.54
Maize 4 passes	50.14	34.84	15.30	14.65
Maize 8 passes	48.06	22.46	25.60	19.23
Pastures 2 passes	54.42	53.32	1.10	1.22
Pastures 4 passes	51.19	50.39	0.80	0.31
Pastures 8 passes	50.33	49.73	0.60	0.00
Native savanna	45.58	34.18	11.40	8.13
Forest	52.30	52.30	0.00	0.00

Effects of tillage systems on soil physical properties, root distribution and maize yield on a Colombian acid-savanna Oxisol

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Acid-soil tropical savannas cover 243 million hectares (Mha) in South America. They are one of the most agriculturally rapidly expanding frontiers in the world. In Colombia, they cover an area of 17 Mha and are locally known as the "Llanos". In 1993, a long-term field experiment on sustainable crop rotation and ley farming systems was initiated on a Colombian acid-savanna soil to test the effects of grain legumes, green manures, intercrops and leys as possible components that could increase the stability of systems involving annual crops. The study has lasted for almost two rotational cycles, recognizing the fact that degrading or beneficial effects of various agricultural practices are always very small and only show up over long periods of time. Alternative systems, which reverse the deleterious effects of monocultures, are required and biophysical measures of sustainability need to be developed as predictors of system performance and health. Integration of crop/livestock systems (Agropastoralism) has been shown to be a highly successful strategy for intensifying agricultural production sustainably and reversing problems of degradation.

The challenge in sustainable crop rotation systems is to optimize short-term productivity while maintaining long-term soil fertility. The situation becomes even more complex when more than two crops are involved in the rotation. Appropriate tillage practices and incorporation of leguminous crops into the rotation can sustain productivity. Legume roots have been found to be efficient in acquiring P and Ca in low fertility acid savanna soils. Here we report the results from the sixth (6^{th}) year of the experiment and one year after implementation of the no-till and minimum tillage systems, during the second 5-year phase, focusing on maize-based systems. The major objective of this study was to determine the effects of no tillage and minimum tillage on (i) soil physical properties, (ii) root distribution, and (iii) maize grain yield on an acid-savanna soil under different agropastoral treatments.

Studies were carried out at the CIAT-CORPOICA experimental station, Carimagua (4°37'N, 71°19'W and 175 m altitude) on the eastern plains of Colombia (Llanos orientales). Measurements were made in selected treatments of the long-term field experiment established in 1993 to investigate sustainable crop rotation and ley farming systems for the acid-soil savannas (CULTICORE experiment). The experimental design was a split-plot with four randomized blocks (replications), with main plots assigned to upland rice-based (fertilizer lime) systems or maize-based (remedial lime) systems. Only results from maize-based systems for the cropping year 2000 are reported in this study. This was the sixth year of rotational cropping after establishment of the experiment, but one year after implementation of the no-till (NT) and minimum tillage (MT) systems. The maize-based systems include the following treatments: maize monoculture (MMO), maize-soybean rotation (MSR), maize-soybean green manure rotation (MGM), native savanna (control) (NSC) and maize-agropastoral rotation (*Panicum maximum* with forage legumes) (MAP). Tillage system NT in this study means that the plots were subjected to conventional tillage (CT) during the first 5-year period and were then sown with a direct-drilling sowing machine, herein referred to as direct seeding i.e. there was no intervention in the soil before planting. Soil physical parameters measured in this experiment included bulk density, total porosity, field moisture content and volumetric moisture content at 0, 7.5, 100 and 1500 kPa suction levels. Root samples were collected at 72 months (6 years) after establishment of the long-term experiment. This was done using the root coring method. Grain yields of maize were recorded after harvest. The grain yields were obtained by manual harvesting from each plot, in 5 rows of maize of 10 m long (4m x 10m (40 m^2)). Grain weights were adjusted to 19% of moisture content.

Because of differences in the amount of residue and the intensity of tillage, different tillage systems affect the physical properties of soil such as water content, bulk density, penetration resistance and soil porosity. Changes in soil physical properties might develop slowly after initiation of conservation tillage. Few significant results between NT and MT systems were obtained for bulk density under MSR (at the 0-5 cm soil layer); MMO, NSC and MAP (at the 5-10 cm soil layer); and MAP (at the 10-20 cm soil layer). Direct seeding (NT) generally had lower bulk density and higher total porosity for all agropastoral treatments and soil layers as compared to the MT system. On average, within each soil layer and across all agropastoral treatments, field moisture content and volumetric moisture content at all suction levels were similar for both tillage systems. In both tillage systems and under all agropastoral treatments, there was a decrease in volumetric moisture content with increasing water suction ($P < 0.05$)

The influence of NT and MT on distribution of maize roots under different agropastoral treatments is summarized in Table 8. The MT system seemed to improve root length. The average root length for NT agropastoral treatments was 0.70, 0.47, 0.37 and 0.33 km m^{-2} for the 0-5, 5-10, 10-20 and 20-40 cm soil layers, respectively. For the MT agropastoral treatments, it was 0.84, 0.55, 0.58 and 0.49 km m^{-2}. On the other hand, within the MT system, higher root length results were obtained under MSR agropastoral treatment at the 5-10 cm soil layer and also under MGM at the 20-40 cm soil layer. There was a decrease in maize root length with increasing soil depth for all tillage systems and agropastoral treatments ($P < 0.05$). Enhanced biological activity and increased nutrient availability has been reported to influence root distribution in the topsoil.

The MT system also appeared to improve root biomass of maize in the 0-5 and 20-40 cm soil layers. The average values were 467 and 43 kg ha^{-1} for the 0-5 and 20-40 cm soil layers, respectively, for NT and 595 and 56 kg ha^{-1} for the same soil layers for MT (Table 8). There was a decrease in maize root biomass with increasing soil depth within both NT and MT systems ($P < 0.0001$). Higher root biomass adds organic matter and improves soil fertility through rapid turn over and addition of nutrients. This could contribute to improved crop yields. On average, specific root length was higher under MT as compared to NT system. These results highlight the fact that tropical forage pastures in association with forage legumes (under treatment MAP) had developed a finer root system and therefore are most likely to positively influence productivity under this treatment.

Between the two tillage systems, higher maize grain yields ($P < 0.1$) were obtained under NT system treatments MMO, MSR and MGM as compared to the same treatments under MT system (Table 9).

Native savanna (control) (treatment NSC) consistently produced the lowest maize grain yields. Within the NT system, treatments MMO, MSR, MGM and MAP showed higher maize grain yields as compared to NSC, with MGM giving the highest yield. The trend was MGM > MAP > MSR > MMO > NSC (Table 5). The values for maize grain yield ranged from 1280 kg ha^{-1} (under NSC) to 4705 kg ha^{-1} (under MGM). These results indicate that the MGM treatment with NT soil conditions were adequate for implementing the no-till system. The average maize grain yield under all the NT system agropastoral treatments was 3566 kg ha^{-1}. Within the MT system, treatment MAP showed higher maize grain yield as compared to the other agropastoral treatments. The trend was MAP > MSR > MGM > MMO >NSC. The values for maize grain yield ranged from 1150 kg ha^{-1} (under treatment NSC) to 4117 kg ha^{-1} (under treatment MAP). The average maize grain yield under all the MT system agropastoral treatments was 2473 kg ha^{-1}.

Table 8. Effects of no-till (NT) and minimum tillage (MT) on root distribution of maize under different agropastoral treatments[#]

Soil depth (cm)	Agropastoral Treatment	Root length km m^{-2}		Root biomass km ha^{-1}		Specific root length m g^{-1}	
		NT	MT	NT	MT	NT	MT
0 – 5	MMO	0.75 a	0.87 a	494 a	660 a	15 a	13 a
0 – 5	MSR	0.49 a	0.69 a	468 a	508 a	11 a	14 a
0 – 5	MGM	0.43 a	0.58 a	456 a	658 a	9 a	9 a
0 – 5	NSC	0.95 a	0.84 a	513 a	401 a	19 a	21 a
0 – 5	MAP	0.86 a	1.23 a	403 a	747 a	21 a	17 a
5 – 10	MMO	0.45 a	0.50ab	57 ab (b)	84 a	79 a	60 a
5 – 10	MSR	0.51 a	0.84 a	57 ab (b)	83 a	90 a	101 a
5 – 10	MGM	0.26 a	0.31 b	46 b (b)	52 a	57 a	60 a
5 – 10	NSC	0.16 a	0.47 ab	§188 ab(ab)	99 a	32 a	48 a
5 – 10	MAP	0.96 a	0.61 ab	*§275 a (a)	75 a	§35 a	81 a
10 – 20	MMO	0.41 a	1.03 a	§53 a	102 a (a)	77 a	101 a
10 – 20	MSR	0.54 a	0.62 a	92 a	61 ab (ab)	59 a	102 a
10 – 20	MGM	0.26 a	0.27 a	*§242 a	52 b (b)	*§11 b	52 a
10 – 20	NSC	0.16 a	0.35 a	§142 a	49 b (b)	*§11 b	71 a
10 – 20	MAP	0.46 a	0.61 a	53 a	56 ab (b)	87 a	109 a
20 – 40	MMO	0.39 a	0.35 b	70 a	48 a	56 a	73 a
20 – 40	MSR	0.17 a	0.39 b	31 a	43 a	55 a	91 a
20 – 40	MGM	*§0.20 a	0.96 a	25 a	72 a	80 a	133 a
20 – 40	NSC	*§0.54 a	0.15 b	62 a	54 a	87 a	28 b
20 – 40	MAP	0.33 a	0.61 ab	27 a	65 a	122 a	94 a

[#]For a given root parameter and depth as well as tillage system, means within a column followed by the same letter (s) are not statistically significantly different, using the LSD test at $\alpha = 0.05$ and $\alpha = 0.1$; the letter(s) in parentheses show significant statistical results at $\alpha = 0.1$ at the given soil depth and tillage system; the asterisk (*) and paragraph (§) indicate a significant statistical difference in the concerned parameter between the corresponding two tillage systems (i. e. NT and MT) for a given agropastoral treatment at $\alpha = 0.05$ and $\alpha = 0.1$, respectively.

It is clear from the above results that the NT system, on average, produced higher maize grain yields as compared to the MT system and that treatment NSC produced the lowest yield among all the agropastoral treatments. Crop production on tropical and subtropical acid soils is normally limited by aluminum toxicity. This could have been the possible cause of the very low maize grain yields under treatment NSC, since the soils had very high aluminum (90%) saturation.

Maize grain yield results from this investigation indicate that the agropastoral treatments under NT, as compared to the same treatments under MT system, had created soil conditions adequate for implementation of the no-till system on the Colombian savanna Oxisols. The positive influence of legumes in the rotations was thus realized in this study. This would be good news for the resource-poor farmers in this region, as they would easily adopt this relatively cheaper technology for increased soil productivity and environmental conservation. Maize yields on native savanna soils were markedly lower than the rest of the agropastoral treatments, indicating the need for improved soil conditions in subsoil layers for root growth of maize.

Table 9. Effects of no-till (NT) and minimum tillage (MT) on maize grain yield under different agropastoral treatments[#]

Agropastoral treatment	Grain Yield -------------------kg ha^{-1}-----------------------	
	NT	MT
MMO	*§3802 a	2035 bc (c)
MSR	§3804 a	2691 b (b)
MGM	*§4705 a	2370 b (bc)
NSC	1280 b	1150 c (d)
MAP	4239 a	4117 a (a)

[#]For each tillage system, means within a column followed by the same letter (s) are not statistically significantly different, using the LSD test at $\alpha = 0.05$ and $\alpha = 0.1$; the letter (s) in parentheses show significant statistical results at $\alpha = 0.1$ within the given tillage system; the asterisk (*) and paragraph (§) indicate a significant statistical difference in yield between the corresponding two tillage systems (i. e. NT and MT) for a given agropastoral treatment at $\alpha = 0.05$ and $\alpha = 0.1$, respectively.

Inorganic and organic phosphorus pools in earthworm casts (Glossoscolecidae) on a Brazilian rainforest Oxisol

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We compared differences in soil phosphorus fractions between large earthworm casts (Family Glossoscolecidae) and surrounding soils, i.e., Oxisols in 10 year-old upland agroforestry system (AGR), pasture (PAS), and secondary forest (SEC) in the Central Brazilian Amazon. AGR and PAS both received low-input fertilization and SEC received no fertilization. We found that earthworm casts had higher levels of organic hydroxide P than surrounding soils, whereas fertilization increased inorganic hydroxide P. Inorganic P was increased by fertilization, and organic P was increased by earthworm gut passage and/or selection of ingested materials, which increased available P (sum of resin and bicarbonate fractions) and moderately available P (sum of hydroxide and dilute acid fractions), and P fertilizer application and land-use increased available P. The use of a modified sequential P fractionation produced fewer differences between earthworm casts and soils than were expected. We suggest the use of a condensed extraction procedure with three fractions (Available P, Moderately Available P, and Resistant P) that provide an ecologically based understanding of the P availability in soil. Earthworm casts were estimated to constitute 41.0, 38.2, and 26.0 kg ha^{-1} of total available P stocks (sum of resin and bicarbonate fractions) in the agroforestry system, pasture, and secondary forest, respectively.

Evaluation of *Brachiaria humidicola* accessions for nitrification inhibition ability

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We have reported earlier that *B. humidicola* CIAT 679 has the ability to inhibit nitrification by releasing inhibitory activity from roots (NI activity). This is based on evaluation of germplasm accessions that have apomictic mode of reproduction. This makes it extremely difficult to use this ability in a breeding program to transfer the ability to inhibit nitrification to other *Brachiaria* grasses that lack such ability unless we find genetic variability for this trait among sexual accessions of *B. humidicola*.

During this year, we evaluated 11 accessions of *B. humidicola*, that are believed to have the sexual mode of reproduction, along with the standard cultivar of CIAT 679 and *Panicum maximum*. Sexuals of *B. humidicola* can be used in a *Brachiaria* breeding program as they can be hybridized with other *Brachiaria* species. Plants were grown in a sandy loam Oxisol from the Llanos (Matazul) of Colombia (1 kg of soil/pot) under greenhouse conditions. The details of growing conditions and culture details were similar to that reported in the Tropical Grasses and Legumes annual report of 2004. After 120 d of growth, plants were removed from soil, and root exudates were collected and NI activity was extracted as described earlier (see annual report of 2004) and quantified using the modified bioassay that was developed at JIRCAS (see annual report of 2004 for details on the bioassay methodology).

Total NI activity released from roots of four plants during a 24 h varied from 62.4 to 207.2 AT NI among the sexual accessions of *B. humidicola*. The standard cultivar of CIAT 679 released about 66.4 AT NI. The NI activity released from *P. maximum* is only about 0.55 AT NI during 24 h period, thus confirming our earlier observations that this tropical grass lacked such NI ability.

Our results indicated that most of the sexual accessions of *B. humidicola* have similar NI ability to that of standard cultivar CIAT 679, and that only one sexual accession has nearly three times NI activity released compared to that of the standard cultivar. Thus, the NI ability of *B. humidicola* CIAT 679 is not confined to the accessions that have apomictic mode of reproductive behavior, but exists also in the accessions that have sexual mode of reproductive behavior. Our results indicate that some of these sexual accessions can be used as a source of NI trait for the *Brachiaria* breeding program to regulate NI activity to improve N use efficiency in pasture systems.

Field validation of the phenomenon of nitrification inhibition from *Brachiaria humidicola*

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A range of Nitrification Inhibition (NI) activity has been measured for diverse accessions of *B. humidicola* and other tropical grasses under glasshouse conditions, as part of collaborative research between JIRCAS and CIAT. As a continuation of these research efforts, a long term field experiment was planned to validate the phenomenon of NI under field conditions and to test the hypothesis that the NI activity is a cumulative factor in soils under species that release the NI activity from root exudates. Given the vast areas currently grown in the tropics on tropical grasses, an understanding of the NI process and the possibility of managing it to improve N use efficiency, reduce nitrate pollution of surface and groundwaters as well as reduce net impact on global warming through reduced emissions of nitrous oxide, could have potentially global implications. Various tropical grasses showing a varying degree of NI activity were selected for the experiment and a soybean crop and a grass (*P. maximum*) that lacks the NI activity were selected as controls.

The experiment was initiated in September 2004 at CIAT-HQ at Palmira, Colombia on a fertile clayey Vertisol (pH 6.9), and with an annual rainfall of 1000 mm and mean temperature of 25 C. Two accessions of *B. humidicola* were used: the commercial reference material CIAT 679, which has been used for most of our previous studies, and the high NI activity *B. humidicola* accession CIAT 16888. The *Brachiaria* Hybrid cv. Mulato was included for having moderate NI activity and *Panicum maximum* var. common was used as a negative non-inhibiting control. Soybean (var. ICAP34) is also used as a negative control due to its known effect on promoting nitrification. A plot without plants is used as an absolute control.

Treatments were placed in plots of 10 m x 10 m with three replications and distributed in a completely randomized block design. Soybean was planted from seeds and the grasses were propagated from cuttings. Soybean was inoculated with the Rizhobium strain CIAT 13232 to favor biological nitrogen fixation. Irrigation was provided to the field as required and two applications of broadcast fertilization were made at 30 and 60 days after planting on each plot, except within two 1 m^2 subplots demarcated in each plot, where the same levels of fertilizer were applied in solution to favor a more homogeneous distribution of the applied nutrients within the soil. Each application consisted of an equivalent dose of (kg ha^{-1}): 48N, 24K, 8P, 0.2 Zn, 0.2 B. The nitrogen source was ammonium sulfate. Weed control was done using Glyphosate in the bare soil plots and in the soybean plots before planting. During the soybean growing cycle manual weeding was done in such plots.

At harvest, soybean plants including roots were removed from the field when they had reached full maturity and the grain was already dry. The plants were separated into roots, shoots and grain, and a representative subsample taken for measuring dry matter content and N analysis. Plants of *P. maximum* were cut at approximately 20 cm height twice during the crop cycle. From each cut a representative subsample collected for dry weight and N analysis. The Brachiaria Hybrid cv. Mulato was cut at 20 cm height while the *B. humidicola* accessions were cut at 10 cm height. Similar procedure used for cv. Mulato was used for *P. maximum*. At harvest time, soil was carefully collected in the rizhopane of all species with an auger from the top 10 cm of the soil within each subplot. Four samples were collected in each sub plot and pooled to obtain a composite sample. Samples were carefully managed and only the soil adhered to the roots was removed and used for soil analysis. Once the rhizosphere soil was collected, it was allowed to air dry and then was finely ground to <0-1 mm mesh. Soil was analyzed for nitrate and ammonium content using KCl extracts and colorimetric determination. Fresh rhizoplane soil was used for microbial counting of nitrifier organisms. Gas samples for measuring N_2O fluxes were collected monthly. Once a year, soil incubation studies were conducted using rhizosphere soil, to monitor nitrogen dynamics and fluxes of N_2O.

So far two soybean crops have been harvested (February and August, 2005). In this report we present the data collected during the second cropping season and the accumulated fluxes of N_2O over one year. In Figure 8 we present the biomass harvested during the second crop cycle (April- August, 2005). Total yield of *P. maximum* and the *Brachiaria* hybrid Mulato were similar and clearly higher than the biomass from other species. Soybean had a total biomass slightly lower that the *B. humidicola.* Due to better plant coverage, biomass production of all the grasses but more particularly of the *B. humidicola* accessions was higher than during the initial cropping season.

Total N uptake by plants (in the harvested components) followed a similar trend of biomass accumulation. It is evident that both *P. maximum* and the Hybrid Mulato are extracting more N than what is being added as fertilizer, and consequently a net N mixing from the soils is occurring. Soybean is balanced regarding N application/uptake while the *B. humidicola* plots are removing less N than what is being added as fertilizer. The grain yield of soybean was similar in the two cropping seasons (1.6 Mg ha^{-1}) which is slightly lower that the commercial average in the region.

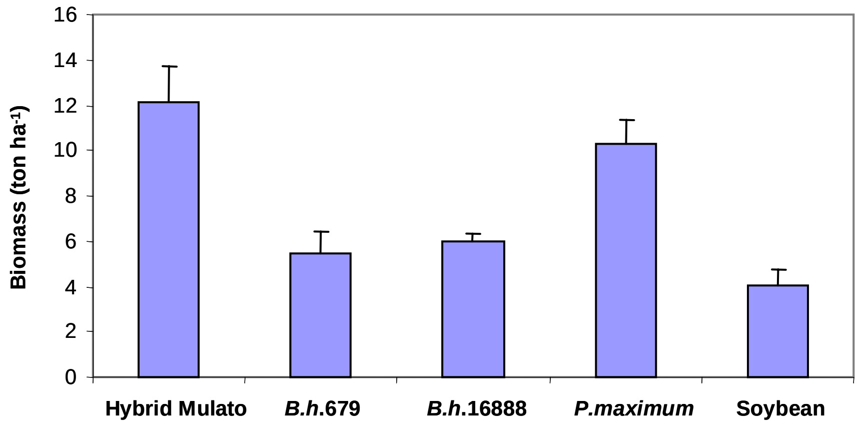

Figure 8. Total biomass harvested during the second cropping cycle (April- August 2005).

Soil Nitrate. In Figure 9 we show the nitrate levels in the top soil at harvest time. As expected the bare soil plots showed higher levels of nitrate more likely as a result of lack of plant N uptake. The soybean plots as well as the plots under the Brachiaria hybrid Mulato and *P. maximum* also had high levels of soil nitrate, while the *B humidicola* accessions clearly showed lower nitrate concentrations. The lower N uptake by 2 accessions of *B. humidicola* suggest a lower rate of nitrification with these two grasses or alternatively higher nitrogen losses.

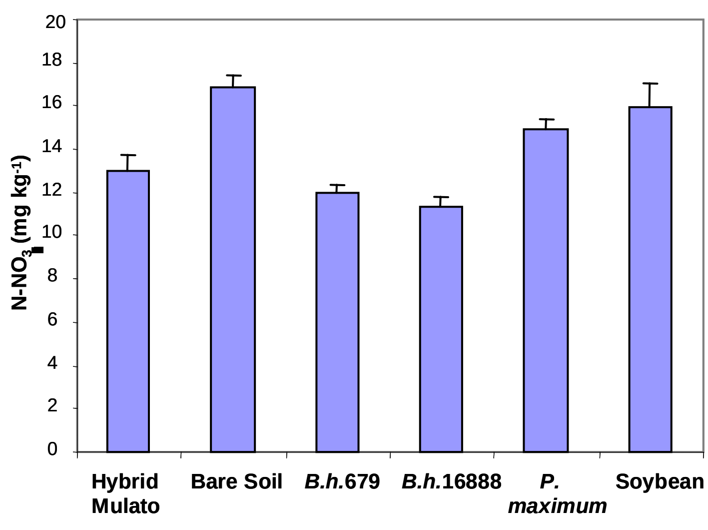

Figure 9. Nitrate levels in the top soil (0-10 cm) at harvest time.

Nitrous oxide emissions. In Figure 10, we show the accumulated fluxes of Nitrous Oxide (N_2O) over the period of September 2004 – August 2005. Annual emissions of N_2O were significantly lower in plots with *B. humidicola* and *P. maximum* than in the other plots. Fluxes were highest in the bare soil plots. These results support the view that *B. humidicola* is effectively inhibiting the nitrification process. However, *P. maximum* is also resulting in lower net emissions of N_2O but this may be attributable to the much higher nitrogen uptake by the plants which may limit the total amounts of N available for nitrification, assuming that the grass is able to take up N from the soil in ammonium form.

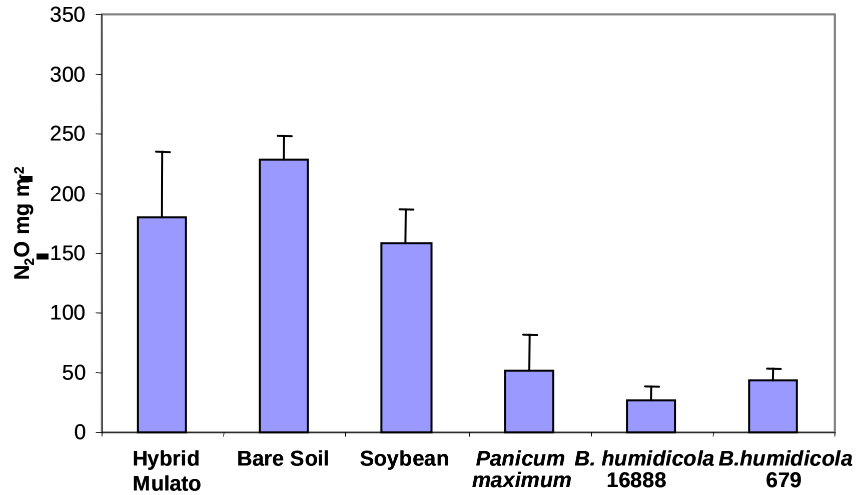

Figure 10. Accumulated fluxes of N_2O over one year period (September 2004 – August 2005). Two cropping cycles were included.

Soil Nitrification rates. Fresh rhizosphere soil was incubated to assess their mineralization rates in which soil samples are incubated with appropriate levels of ammonium and phosphate to favor nitrification. Chlorate is added to block the conversion of nitrite to nitrate and rates of nitrite accumulation (which are easier to measure than nitrate accumulation) are registered over time. In Figure 11 we show the results from the incubation test. The trend was similar than that with the N_2O fluxes. Both *B. humidicola* and *P. maximum* showed significantly lower nitrification rates than bare soil and soybean.

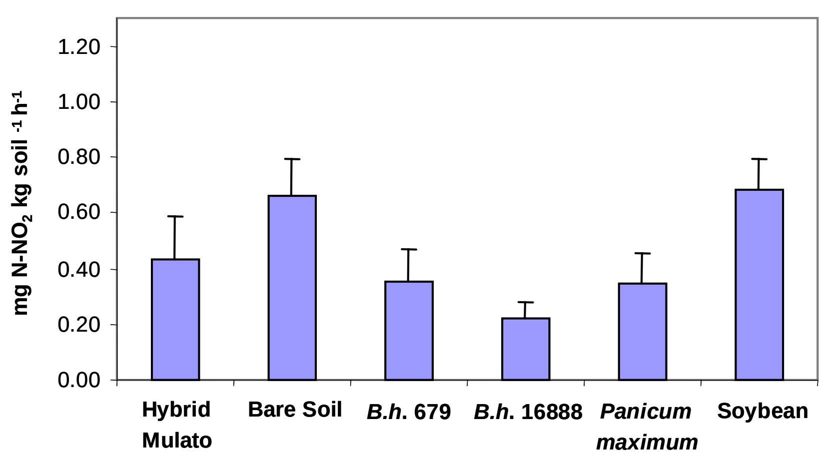

Figure 11. Nitrification rates from incubated soils.

No clear trend was observed for nitrate and ammonium levels in soil extracts. However, the significantly lower levels of inorganic soil under *B humidicola* suggest however that this species is likely favoring the flow of applied N into organic pools in the soil (Microbial N and Soil organic matter-N). Another indirect indication of this comes from the relatively low levels of nitrate estimated to be leached. This may need to be investigated in more detail in subsequent crop cycles. The incubation method to estimate nitrification rates used for this study is highly sensitive to detect even small differences in nitrification rates. In the next crop cycle, attempts will be made to monitor more frequently the nitrification rate of the plots during the crop season.

The total amount of N lost to the atmosphere as N_2O in the bare soil plots corresponds to approximately 1.6% of the applied fertilizer-N. This figure falls within the range reported in the literature for tropical soils. With *B. humidicola* net N_2O emissions were 12-20% less than the bare soil plots. This highlights the potential of these grasses in contributing to mitigation of climate change due to greenhouse effects.

Enhancing the productivity of crops and grasses while reducing greenhouse gas emissions through bio-char amendments to unfertile tropical soils

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Tropical savannas of Africa and Latin America represent the last frontier where agriculture can expand in the near future. The land is however dominated by very acid and infertile soils, which limit the adaptation and productivity of most crops and forages. Despite that liming and fertilizers could overcome these constraints, frequently they are not available or are too expensive and have had only limited use. In the Amazon rainforest, under similar soil conditions, indigenous knowledge generated millennia ago, lead to the creation of the so called Amazonian Dark Earths: highly productive and sustainable soils built through mixing infertile native soils with charcoal (bio-char), fish bones, nut shells etc. There is a growing interest to replicate these Dark Earths in other tropical environments where low fertility soils are predominant. There is a growing number of reports showing that in several soil types and climatic conditions, the use of bio-char in soils result in a significant increase in the productivity of a wide range of crops. Preliminary glasshouse experiments showed that the use of bio-char as amendment in soils from acid savannas resulted in large increases in biomass and yield of soybean and grasses growing in pots. In order to assess the effect on crop productivity under field conditions of amendments of soils with bio-char in the acid savannas of Colombia, a long-term field experiment was established in 2002. Here we present some of the results from that experiment.

The experiment was located on an clay-loam oxisol (Typic Haplustox) at the Matazul private farm in the Eastern Colombian Plains (4°19'N, 72°39'W). Annual rainfall is 2200mm and average annual temperature is 26°C. Plots were established after burning native vegetation, following farmer practices in the region. Lime was applied (2000 and 500 kg ha^{-1} for the crop and pasture plots respectively, the native savanna plots did not receive any lime or fertilizer application). One month after lime application, three levels of bio-char were applied to the plots: Control (0), 8 Mg bio-char ha^{-1} and 20 Mg bio-char ha^{-1}. The bio-char was produced locally from wood of mango trees using traditional methods. The bio-char was ground to <2mm, broadcasted on the soil surface and then incorporated by disking to 5 cm depth. Four months later, at the beginning of the rainy season, maize (Cultivar H-108) was sown as well as *Brachiaria dictyoneura* (var Llanero). Native savanna was allowed to re-grow on some of the plots. Experimental plots are $20m^2$ (4 x 5m) each and each treatment has 3 replications within a randomized complete block design. The maize plots received annual fertilizer applications equivalent to (per hectare basis) 160 kg N, 40 kg P, 60 kg K, 15 kg Mg and also micronutrients. The grass plots received annual doses equivalent to 30 kg N, 10 kg P and 15 kg K ha^{-1}. Periodically, the grass and the native vegetation (mostly native grasses) were cut to a height of 10 cm simulating grazing and the biomass produced in each interval was registered. Maize was harvested at full grain maturity. Annually soil samples are collected at various soil depths to assess several physicochemical parameters Gas exchange between the soil and the atmosphere was monitored monthly over a three-year period using the closed chamber method. Gas samples were analyzed for CO_2, CH_4 and N_2O using a gas chromatograph with ECD and FID detectors.

Table 10 shows values of selected soil parameters two years after the addition of bio-char. pH increased though not significantly in all plots receiving bio-char as compared with the control. Not significant differences were observed in the Redox potential of the soils, but clear increases in the availability of P and K were found in response to bio-char additions. No net change in total N in the soils was registered, though reduced nitrogen availability to plants may be anticipated as bio-char can adsorb inorganic N. The carbon content in the soils that received bio-char increased significantly and stays approximately constant over time (inter-annual data not showed). This suggests a very low turnover rate of the applied C in the soil despite very high temperatures and annual rainfall that would be expected to accelerate the breakdown of the applied bio-char. This amendment seems therefore to have very large residence times in the soils confirming its potential as a toll for long term C sequestration in soils. Despite that the bio-char was incorporated in the top 5 cm of the soil a significant migration to lower soil layer is evident from the ^{13}C data. ^{13}C of the applied bio-char has an isotopic ^{13}C label of approximately –26%o, while the ^{13}C label of the soil organic carbon is very homogeneous at approximately –12.5%o. We used ^{13}C signatures of the soil to track movement of bio-char in the soil profile. The bio-char migration has proceeded faster in the savanna plots followed by the pasture plots, while in the crop sites very little migration has occurred. Reasons for this are currently being investigated as well as the influence of bio-char on soil hydraulic functions and nutrient leaching.

Table 10. Changes in selected soil parameters after 2 years of Bio-char additions to soils.

Plant type	**Depth** (cm)	**Bio-char dose** (mg ha^{-1})	**pH**	**N-Total** (mg kg^{-1})	**P-Brayll** (mg kg^{-1})	**K** (cmol kg^{-1})	**% C**	**δ^{13}C**
Savanna	0 – 5	0	4.29a	1306.22b	3.00b	0.06b	1.89b	-12.83b
Savanna	0 – 5	20	4.38a	1490.32a	3.14a	0.09a	2.63a	-14.02a
			ns	**	***	***	***	**
Savanna	5-10	0	4.3a	1403.5a	2.76b	0.04525b	1.58b	-12.5b
Savanna	5-10	20	4.3a	1320.86a	3.63a	0.0648a	2.76a	-18.03a
			ns	Ns	**	***	**	***
Pasture	0 – 5	0	4.41a	1421.44a	3.12a	0.07b	2.01b	- 12.97 b
Pasture	0 – 5	20	4.45a	1505.75a	3.46a	0.10a	2.65a	-15.86a
			ns	Ns	*	***	***	***
Pasture	5-10	0	4.37a	1358.81a	2.49b	0.03b	1.74b	-12.3b
Pasture	5-10	20	4.42a	1338.99a	3.05a	0.07a	2.19a	-13.27a
			ns	Ns	***	***	***	***
Crop Rotation	0 – 5	0	4.1a	1625.89a	7.48a	0.12a	2.29a	-12.42a
Crop Rotation	0 – 5	20	4.34a	1321.02b	7.37b	0.18a	2.36a	-13.01a
			ns	***	***	ns	ns	ns
Crop Rotation	5-10	0	4.28b	1397.49a	3.83a	0.12a	2.5a	-13.15a
Crop Rotation	5-10	20	4.92a	1207.66b	3.42a	0.09b	2.21b	-12.78a
			**	**	ns	**	**	ns

For a given soil depth and plant type, values followed by the same letter indicate non significant differences ($P<0.05$)

As indicated in Figure 12 and Table 11, additions of even low doses of bio-char to soils results in a net cumulative increase in total biomass of maize, improved pasture and native savanna vegetation. Yields of maize were similar in all treatments during the initial year but significantly increased due to bio-char use in the two subsequent years. In the third year, yields increased from 5.7 Mg ha^{-1} (control) to 6.6 and 7.3 Mg ha^{-1} for the low and high dose of bio-char respectively. Forage production from *B. dictyoneura* increased by 26% and 55% in the second year relative to the control in the low and high bio-char plots respectively. Total biomass production on the native vegetation trials was slightly increased from 2.9 Mg ha^{-1} (control) to 3.8 Mg ha^{-1} in the high bio-char dose, but was similar to the control at the low dose. The reason for the increase in plant total biomass and productivity can be attributed to increases in the availability of soil nutrients (P, K and probably some micronutrients) as well as changes in the cation exchange capacity of the soils which are being investigated. Higher soil moisture retention in the soil is another feasible explanation that will be confirmed by ongoing research. The effects of bio-char addition remain after three years and show that the positive impact may last even longer, pointing to a sustainable increase in soil quality.

Table 11. Effect of Bio-char additions on aerial biomass (Mg ha^{-1}) of pastures and Native Savanna vegetation
.

Bio-char dose (Mg ha^{-1})	***B.dictyoneura***			**Native Savanna**		
	2003	**2004**	**2005**	**2003**	**2004**	**2005**
0	0.72	1.41	4.73	0.95	1.84	2.91
8	1.35	1.75	5.66	1.72	2.16	3.84
20	1.10	2.60	5.97	1.94	2.22	3.84

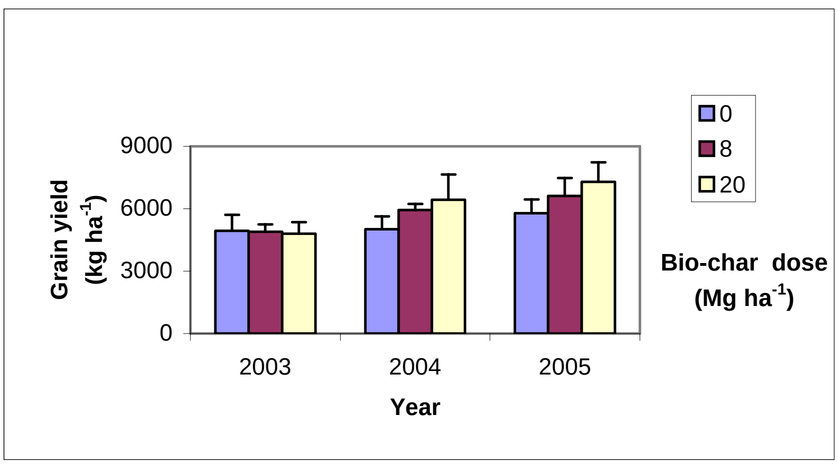

Figure 12. Yields of maize as affected by increasing doses of bio-char in the acid soil savannas of Colombia.

Fluxes of greenhouse gases: The use of bio-char resulted in a net reduction of net annual emissions of nitrous oxide , and also methane from soils as well as net increases in soil carbon. During the initial year, annual methane sinks by soils were increased on average 200 mg $CH_4.m^{-2}$ in all high bio-char plots relative to the controls, while N_2O emissions were reduced on average 15 mg N_2O m^{-2}. Most of the applied C in the bio-char has long residence times in the soil and consequently constitutes a feasible option to store large quantities of C in the soils on the long term. Overall, the use of bio-char results in a net decrease in the integrated Global Warming Potential from the studied soils.

This study indicates that the use of bio-char in acid soils of very low natural fertility is able to increase crop and plant yield and constitutes a valuable tool to increase soil quality of infertile soils. Biochar also constitutes a new tool to mitigate climate change through long term carbon sequestration in soils and net reduction of methane and nitrous oxide emissions from the soils. Currently an economic analysis to assess the financial feasibility of using bio-char as soil amendment is being conducted through a collaboration with the Universidad de los Andes.

Output target 2006

➢ ***Standard methods for BGBD (belowground biodiversity) inventory published***

Published work

BGBD (2005). Standard project methods for the inventory of below-ground biodiversity, BGBD publication, TSBF, Nairobi, Kenya, CD-ROM.
The CSM-BGBD project is carrying out an inventory of below-ground biodiversity in various benchmark areas in seven tropical countries using standard methods. Standard methods were proposed and accepted during the annual meeting that was held in Embu, Kenya, from February 23rd -29th, 2004. In the report of the annual meting these methods are described, also a CD was distributed for internal use within the project. TSBF issued a CD-ROM with the methods not until the beginning of 2005, with the standard methods for the inventory of BGBD. The CD contains the methods for the inventory of Arbuscual Mycorrhizal Fungi (AMF), ectomycorrhiza, Legumenosae Nodulating Bacteria (LNB), macrofauna, mesofauna, fruitflies, nematodes, entomopathogenic nematodes, phytopathogenic fungi as well as the scheme for taking point samples. The CD contains some background articles on molecular techniques for the identification of AMF and rhizobia.

Fátima Moreira and David Bignell (eds), (2005). Standard methods for the assessment of soil biodiversity in the context of land use practices. Report of the Annual Meeting April 2005, Part B. BGBD report series, TSBF-CIAT, Nairobi, Kenya, p. 56;
Jeroen Huising and Peter Okoth (eds.), (2005). Report of the BGB project Annual Meeting April 2005. BGBD report series, TSBF-CIAT, Nairobi, Kenya, p. 289.
The methods referred to above were compiled in a report that was issued as part B to the report of the annual meeting of the BGBD project in Manaus, April 11- 16, 2005. The report is entitled "Standard Methods for the Assessment of Soil Biodiversity in the Context of Land Use Practices". The report contains a number of additions to the earlier manuals, especially the ASB Lecture Note 6B, in terms of the sampling design, the use of Winkler bags for sampling of termites, ants and beetles, added section on the sampling of mesofauna, updated method and reference list of leguminosae nodulating bacteria and added section for phytopathogenic, saprophytic and antagonistic fungi. The report is an intermediate report while the project is working on an official publication on standard methods for the inventory of below-ground biodiversity.

A special session at the annual meeting was dedicated to the standard of methods for inventory of BGBD. Papers presented during that session are included in the report of the annual meeting. The report contains a paper from the BGBD team Côte d'Ivoire on the rapid assessment of the abundance and diversity of earthworm communities in tropical ecosystems, making an argument to include 4 monoliths in the standard sampling procedure. It further includes a discussion on the standard methods for inventory of termites and ants, suggesting the use of Winklers bags, mini monoliths for endogeic ants and semi-quantitative transect, supported by data on sampling efficiency, as standard procedure. Further contribution are on procedures for the inventory of mesofauna, methodology for soil nematode diversity (paramers and indices) and a report on the methodology for the assessment of AMF diversity.

UAS, BGBD/TSBF-CIAT (2005), Proceedings of National Workshop on Evolving Appropriate Methodologies for Economic Valuation of Ecosystem Service of Below-Ground Biodiversity, 12th – 13th May, 2005, UAS, Bangalore, India, p 134.
During the workshop methodological issues regarding the economic valuation of below-ground biodiversity were discussed and a number of case studies were presented. Methodological issues included for example "social use values in the presence of negative externalities". A nice overview of conceptual

and methodological issues was presented by Dr. B. V. Chinnappa Reddy. Case studies reported on related to the economic valuation of on-farm soil organic matter losses due to soil erosion in different agro-climatic zones of Karnataka, to the economic impact of striga as parasitic weed below the ground, or to the impact of sustainable agricultural production techniques on BGBD in rice cultivation. The last contribution at the workshop was on a topic of specific relevance to the BGBD project, namely agricultural intensification, ecological irreversibility and BGBD.

Work in progress

Conservation and sustainable management of below-ground biodiversity; Standard methods for assessment of soil biodiversity in the context of land use practices, editors Fatima Moreira and David Bignell.

The project aims to publish a manual on standard methods. The publication will have contributions from various authors on the following topics:

- Sampling strategy and design;
- Macrofauna with separate sections on macro-arthropods, earthworms, termites, ants, beetles, recording and expressing the data and minimum data sets;
- Mesofauna: Collembolans and mites;
- Nematodes;
- Microsymbionts: *leguminosae* nodulating bacteria;
- Mitcrosymbionts: arbuscular mycorrhizas;
- Phytopathogenic, saprophytic and antagonistic fungi;
- Soil borne pests
- Entomopathogenic fungi and nematodes;
- Land use and land management practices
- Soil structural stability

Output target 2006

- ***At least three indicators of soil health and fertility at plot, farm and landscape scales in hillsides of Africa identified***

Published work

P. Tittonell[1], B. Vanlauwe[1], P.A. Leffelaar[2] and K.E. Giller[2] (2005) Estimating yields of tropical maize genotypes from non-destructive, on-farm plant morphological measurements. Agriculture, Ecosystems and Environment 105: 213-220.

[1]TSBF-CIAT,Nairobi, Kenya; [2]Wageningen University, The Netherlands

Abstract: Maize is the main grain crop grown in the highlands of sub-Saharan Africa, on a broad range of soil fertility and management conditions. Important yield variability has been reported at different scales, reflecting the intensity and spatial distribution of growth-limiting and growth-reducing factors. Maize yield estimation represents a valuable tool to assess within-farm variability in soil fertility through crop performance. The objective of this study was to develop mathematical relationships between plant morphological attributes and grain yield of tropical maize genotypes, based on plant allometric characteristics. These models were used to estimate maize yields and the estimates were validated against independent data collected from experimental and farmers' fields in western Kenya. Three commercial hybrids and three local varieties were considered. Multiple linear regression models including plant height and either ear length or ear diameter as explanatory variables, and simple linear regressions including only plant height, were the most accurate to estimate both total aboveground biomass and grain dry matter yields per plant (r^{-2}.76–0.91). Average values for the harvest index ranged between 0.34 and 0.42, varying with the total aboveground biomass produced per plant. Yield estimations on ground area basis for farmers' fields were acceptably accurate. Plant height measurements can be easily taken at any moment after maize flowering and used in simple models to estimate maize yield. This approach proved also a valuable tool to discuss yield variability with farmers.

Work in progress

Integrating scientific and farmers' evaluation of soil quality indicators in Central Kenya

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[1]Kenyatta University, Kenya; [2]TSBF-CIAT, Nairobi, Kenya

A study was conducted to determine farmers' perceptions of soil quality and common soil management practices that influenced soil fertility within farmers' fields in Chuka and Gachoka divisions, Kenya. Soils were characterised by farmers after which they were geo-referenced and sampled at surface depth (0–20 cm) for subsequent physical and chemical analyses, to determine differences within farmers' soil quality categories. Indicators for distinguishing productive and non-productive fields included crop yield and performance, soil colour and soil texture. There were significant differences among soil fertility categories, using parametric techniques (ANOVA) for key soil properties ($p < 0.005$), implying that there was a qualitative difference in the soils that were chacterised as different by farmers. Fertile soils had significantly higher pH, total organic carbon and exchangeable cations and available-N. Factor analysis on 15 soil properties identified 4 main factors that explained 68% of the total variance in soil quality. The four Varimax- rotated factors were designated as contrasts that described soil quality status on farmers fields. The first factor grouped calcium, magnesium and soil pH, while the second component comprised of available nitrogen, organic carbon and total nitrogen. The third factor included plant nutrients mainly extractable phosphorus and available nitrogen, while the fourth factor comprised of soil physical properties (macroaggregates, microaggregates, silt, clay). Soil fertility and crop management practices that were investigated indicated that farmers understood and consequently utilized spatial heterogeneity and temporal variability in soil quality status within their farms as a resource to maintain or enhance agricultural productivity.

Abundance and diversity of macrofauna and soil aggregates in soil of Central Kenya added with organic material.

A Ponce[1], B Vanlauwe[2], M Pulleman[3], L Brussaard[4], and Dendooven[1]

[1]CINVESTAV, Mexico; [2]TSBF-CIAT, [3]CIMMYT, Mexico; [4]Wageningen University,The Netherlands

Soil fauna play an important role in enhancing and sustaining soil productivity through their effect on soil organic matter decomposition and the resulting availability of plant nutrients and macroaggregate formation. Termites and ants are known to be efficient in digesting cellulose and in some case lignified plant materials. Earthworms ingest plat residues and clay minerals. As a result, their casts often have a higher soil organic matter content (SOM) than the surrounding soil. The objective of this work was to evaluate the abundance and diversity of macrofauna and its effect on aggregates formation and turnover for soils amended with different qualities of organic materials in Central Kenya.

Two experimental sites one in the Embu and the other in the Machanga district in the eastern province of Kenya. A field trial was started at both sites in 2002. The fields were cropped under continuous maize and five different residues with different N, lignin and polyphenol content (*Tithonia diversifolia*, *Calliandra colathyrsus*, maize stover, sawdust and manure). The TSBF methodology was used in macrofauna sampling in two layers 0 – 15 cm and 15 – 30 cm. Dry sieving was done for 5 min over a stack of sieves with a mesh size of 10, 2, 1 and 0.25 mm respectively to separate in five different fractions. Finally, wet sieving was done to dry aggregates (from dry sieving) between 2-10 mm, 1-2 mm and 0.25 - 1 mm aggregates.

Termites, ants and earthworms (ecosystems engineers) were the dominant macrofauna in soil at both sites. At Embu, 62, 10 and 14% of the macrofauna were termites, ants and earthworms respectively. At Machanga, 53, 27 and 3% were termites, ants and earthworms respectively (Figure 13). The addition of manure in the soil had a positive effect on the density of earthworms. Termites were found in all plots. Large densities were found in the plots added with vegetable organic material, with the largest value found in soil added with sawdust. The addition of manure resulted in similar densities for termites as found in unamended soil. The density of ants and "Others" was not significantly different between the plots ($p < 0.05$). The remaining fauna were mainly *Araneae, Acari, Annelida, Blattodea, Coleoptera, Chilipoda, Diplopoda, Diptera, Hemiptera, Orthoptera* and *Pseudoscorpionida*. ($p< 0.05$).

Conclusions: Although termites are the dominant species at both sites, clear effects of organic matter inputs could be seen on both the abundance of termites, ants, and earthworms. Aggregate separation through dry and wet sieving techniques will shed some light on the potential effect of these organic resource-driven changes in the abundance of ecosystem engineers on soil structure and its stability.

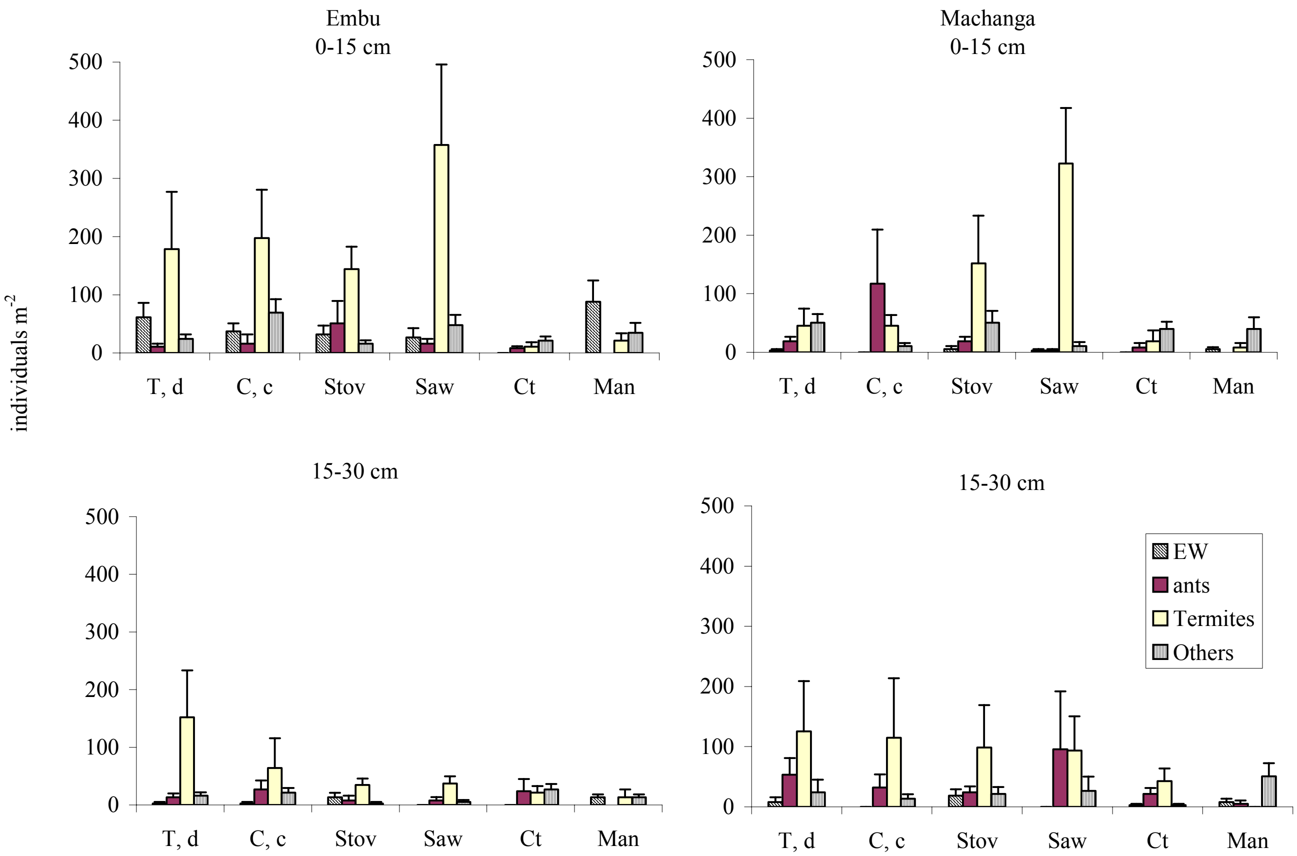

Figure 13. Abundance of specific classes of macrofauna ('EW' means earthworms, termites, ants, and other) in the 0-15 and 15-30 cm of soil at the Machanga and Embu sites. 'T,d' means '*Tithonia diversifolia*', 'C,c' means '*Calliandra calothyrsus*', 'Stov' means 'Maize stover', 'Saw' means 'Sawdust', 'Ct' means 'Control', and 'Man' means 'Manure'. Error bars are Standard Deviations.

Output target 2007

- ***At least three indicators of soil health and fertility at plot, farm and landscape scales in acid soil savannas identified***

Completed work

Soil microbial biomass carbon and nitrogen as influenced by organic and inorganic inputs at Kabete, Kenya

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Soil microbial biomass is the main driving force in the decomposition of organic materials and is frequently used as an early indicator of changes in soil properties resulting from soil management and environment stresses in agricultural ecosystems This study was designed to assess the effects of organic and inorganic inputs on soil microbial biomass carbon and nitrogen overtime at Kabete, Kenya. *Tithonia diversifolia, Cassia spectabilis, Calliandra calothyrsus* were applied as organic resources, and Urea as inorganic source. Soil was sampled at 0-10 cm depth before incorporating the inputs and every two months thereafter and at harvesting in a maize-cropping season. Soil microbial biomass carbon and nitrogen was determined by Fumigation Extraction method (FE) while carbon evolution was measured by Fumigation Incubation (FI) method. The results indicated a general increase in soil microbial biomass carbon and nitrogen in the season with the control recording lower values than all the treatments. Microbial biomass carbon, nitrogen and carbon dioxide evolution was affected by both quality of the inputs added and the time of plant growth. *Tithonia* recorded relatively higher values of microbial biomass carbon, nitrogen and carbon evolution than all the other treatments. A significant difference was recorded between the control and the organically treated soils at the of the season for the microbial biomass nitrogen and carbon dioxide evolution. Both the microbial biomass C and N showed a significance difference ($P \leq 0.05$) in the different months of the season.

Tracing the fate of nitrogen in a humic nitisol under different management practices in Kenya

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The application of nitrogen in a soil under agricultural production is subject to several pathways including de-nitrification, leaching and recovery by the annual crop. This is as well greatly influenced by the management practices, nitrogen source and soil conditions. The main objective of this study was to investigate the loss of nitrogen (N) through nitrous oxide (N_2O) emissions and mineral N leaching and uptake by annual crop as influenced by the N source. The study was carried out at Kabete in Cetral Kenya. Results obtained indicated that nitrous oxide (N_2O) emissions at four weeks after planting were as high as 12.3 μg N m^{-2} hr^{-1} for tithonia treatment and 2.9 μg N m^{-2} hr^{-1} for urea treatment. Tithonia green biomass treatment was found to emit N_2O at relatively higher rate compared to urea treatment. However, considering the rate at which N was applied (20 kg N ha^{-1} and 60 kg N ha^{-1} for urea and Tithonia respectively), it could be concluded that there was a higher rate of N_2O emission in urea treatment than in tithonia treatment. This was only evident during the fourth week after treatment application.

Soil mineral N content at the end of the season increased down the profile. This was evident in the three treatments (urea, tithonia and control) investigated in the study. Urea treatment exhibited significantly higher mineral N content compared to the control at depth up to 100 cm. This could be attributed to the washing down of the nitrate-N from the topsoil accumulating in the lower layers of the soil profile.

However, there was no significant difference in N content down the soil profile between tithonia treatment and the control. It could be concluded that there was no nitrate leaching in the tithonia treatment. Nitrogen recovery by the maize crop was higher in the urea treatment as compared to tithonia treatment. This was also true for the mineral N content left in the soil at the end of the season.

From this study, it was therefore evident that although there is relatively lower N recovery by maize supplied with tithonia green biomass compared to maize supplied with urea, more nitrogen is being lost from the soil-plant system in the urea applied plots than in tithonia applied plots.

On farm tersting of phosphorus availability from phosphate rocks as affected by addition of local organic resources in Western Kenya

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Low soil fertility has been identified as the most significant constraint to increased productivity in Western Kenya. Many years of continuous cultivation have resulted in the depletion of native soil fertility and decline in crop productivity. Soils are generally deficient in nitrogen (N) and phosphorus (P). The obvious strategy is the use of inorganic fertilizers and these are recommended by FURP (1994) and the use of low cost technologies or soil fertility improvement such as rock phosphates (PRs). Although PRs are generally insoluble in water it is thought that their solubility and hence availability of P can be enhanced by their incorporation with organic materials. A study on enhanced solubilization of PRs through incorporation of available organic resources including crop residues was conducted. An experiment was conducted between March and August 2004 at Nyabeda on farm site in Siaya district. It was a split plot experiment with three replicates. The main plot units were Minjingu (MPR) and Busumbu (BPR). Both were applied at a rate of 40 kg P ha^{-1} and a similar rate was used for a standard soluble P source of triplesuperphosphate (TSP) for comparison. N was applied at 75 kg ha^{-1}, with 30 kg applied at planting and 45kg as top dressing. Four local organic materials were used at rates of 1 and 2 t/ha. Control and farmers manure was also included. Planting was done using MBILI intercropping system and two crops were used (Soybeans and Maize). The plots were 4.5m by 5m giving an effective area of 13,875 m. Soil sampling was done monthly for available P and pH analyses to determine solubility of PRs with time. Laboratory analyses were done for Olsen P and pH for soils and total P and N in grains and stovers. Data analyses was done using SPSS 12.0 .1 for Windows and means separated using Duncan' Multiple Range Test (DMRT) at 95% confidence. There were significant differences in the main treatments on maize yields. The control was the lowest yielder with mean of 0.18 t/ha while MPR had a mean of 2.46 Mg ha^{-1} and TSP had a mean of 2.03 t/ha. BPR was not significantly different from farmers manure although they were both different from the control. *Tithonia diversifolia* had the highest effect on maize yields with a mean of 2.75 Mg ha^{-1} compared with TSP with a mean of 2.03 Mg ha^{-1}. The rate of 2t/ha was significantly different from that of 1 t/ha in all treatments except for pyrethrum industrial waste and maize stover. TSP gave the highest Soybean yield of 855 kg ha^{-1} and this was significantly different from all others while the control and BPR had the lowest yields of less than 350 kg ha^{-1}. Pyrethrum industrial waste had the best effect on soybean yield with a mean of 608 kg ha while *Lantana camara* had the lowest yield of the organics with mean of 375 kg ha^{-1}. MPR showed good results as there was no significant difference between it and TSP on yield and could thus be used as an alternative source of P. *Tithonia diversifolia* and pyrethrum industrial waste were the most promising organics.

Tillage effects on maize yield in a Colombian savanna oxisol: soil organic matter and P fractions

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Soil organic matter (SOM) is critical to sustainable agricultural productivity in tropical regions, especially in savanna ecosystems. It is an important factor affecting soil quality and long-term sustainability of agriculture. Together with soil management, tillage in particular, SOM influences many physical, chemical and biological properties in highly weathered Oxisols. Oxisols and Ultisols dominate in the eastern plains of Colombia. These soils are infertile and are extensively and traditionally used for cattle ranching, with low management and almost no purchased inputs. Their productivity is consequently very low. However, long-term crop rotation, combined with appropriate tillage, may restore SOM levels that may increase crop yields in Oxisols.

SOM is a source and sink for plant nutrients and plays a key role in the carbon cycle, since it accounts for the major terrestrial pool of this element (i. e. carbon). Organic matter fractionation has been found to increase the sensitivity to detect changes in SOM due to soil tillage and crop rotations. Size-density fractionation enables assessment of labile pools of SOM that are more sensitive to differences in soil management, land use or cropping practices than soil total C. Of practical significance to soil productivity is the fact that SOM is a major source of organic P. In these highly weathered and high P-sorbing soils, P maintained in organic pools may be better protected from loss through fixation than P flowing through inorganic pools.

P is an important nutrient in relatively short supply in most natural ecosystems and is the primary limiting nutrient for crop production in highly weathered tropical soils. The deficiency is mainly caused by strong adsorption of $H_2PO_4^-$ to Al and Fe oxides and hydroxides (sesquioxides), which turns large proportions of inorganic P into a form that is unavailable to plants. However, plants growing in these soils have access to some P fractions (especially the soluble and moderately soluble fractions) that are best estimated by P fractionation procedures such as the one by Hedley. This procedure involves sequential extraction of inorganic P (Pi) and organic P (Po) with increasingly aggressive reagents. This allows characterization of the different pools of Pi and Po that are supposed to be differentially available to plants. Compared with the other major nutrients, P is by far the least mobile and available to plants in most soil conditions, particularly in Oxisols and is therefore likely to be greatly affected by tillage. Mechanical manipulation of soil during tillage may increase the chances of contact between soil solution or fertilizer-derived P and exposed soil particles and this facilitates the formation of stable insoluble P compounds. Tillage, notably 'no-tillage', affects some chemical characteristics related to soil acidity that may influence P availability, plant growth and yield. Organic matter and P accumulate in the top few centimeters under 'no-tillage' compared with 'conventional tillage', which may reduce Al toxicity. Other nutrients also accumulate near the surface in 'no-tillage' soils, causing increases in the concentration of electrolytes and P sorption. These effects may offset the benefits of SOM and P accumulation on Al toxicity in 'no-tillage' soils.

Recently, interest in long-term experiments has increased worldwide because they are the only means of identifying suitable indicators for early warning of productivity decline and ecosystem damage. Also, long-term data can be used in testing or evaluating predictive models. The objectives of this study were to evaluate the impact of minimum-tillage (reduced harrowing intensity followed by direct seeding), no-tillage (direct seeding) and crop rotation on: a) soil organic matter fractions, b) soil P fractions and c) maize grain yield in a long-term experiment on an acid-savanna soil.

Studies were carried out at the CIAT-CORPOICA experimental station, Carimagua (4^{o}37'N, 71^{o}19'W and 175 m altitude) on the eastern plains of Colombia (Llanos Orientales). The area has two distinct climatic seasons, a wet season from the beginning of March to December, and a dry season from December to the first week of March. The mean annual rainfall and temperature in this area are 2240 mm and 27^{o}C, respectively. Before the beginning of the long-term experiment, the area was under native savanna vegetation (mostly *Andropogon* and *Trachypogon* grasses) and the predominant land use was extensive cattle ranching. Physiographically, the land is generally flat (slope < 5%), typical of the Colombian savanna ecosystem. The soils are deep, have good physical properties but present chemical constraints such as high Al saturation, low organic C, available N and P. They are well-drained silty clay loam Oxisols, and are classified as Isohyperthermic fine-loamy Kaolinitic Tropeptic Haplustox in the USDA soil classification system.

The long-term experiment CULTICORE was established in 1993 to investigate sustainable crop rotation and ley farming systems for the acid-soil savannas. The experimental design was a split-plot with four randomized block as (replications), with main plots assigned to upland rice-based (fertilizer lime) systems and maize-based (remedial lime) systems. Only results for maize-based systems for the cropping year 2001 are reported in this study. This was the seventh rotational cropping after establishment of the experiment, but two years after the implementation of no-till (NT) and minimum tillage (MT) systems. The maize-based system treatments included: a) maize monoculture (MMO), b) maize-soybean rotation (MRT), c) maize-soybean green manure rotation (MGM), d) maize-agropastoral rotation (MAP) and e) native savanna control (NSC) (Table 12). Soybean or green manure rotations occurred within the same year, whereby maize was sown in the first season and soybean in the second season. Pastures were sown simultaneously under maize in 1994 and again in 1998 and were grazed in the intervening 4 years. Native savanna plots were maintained for baseline comparisons and were used as a control to assess the effects of NT and MT on SOM and P fractions and maize grain yield. For the cropped systems, liming was done with 2000 kg ha^{-1} of dolomite prior to establishment of the experiment and maintained thereafter with annual applications of 200 kg ha^{-1}. Each maize crop received 120 kg-N ha^{-1} (split: 40 + 40 + 40), 80 kg-P ha^{-1} and 100 kg-K ha^{-1}. Legumes (soybean or green manure) received 20 kg-N ha^{-1}, 40 kg-P ha^{-1} and 60 kg-K ha^{-1}. Pastures were fertilized bi-annually with 20 kg-P ha^{-1}. The subplots were of size 0.36 ha (200 m x 18 m, 3600 m^2) for maize and soybean, but were 0.72 ha (200 m x 36 m, 7200 m^2) for treatment MAP to allow grazing by cattle and use conventional machinery.

Table 12. Treatment description of the agropastoral/ley farming systems (CULTICORE Experiment, Carimagua)

Treatment	**Agropastoral/ley farming system**	**Description**
MMO	Maize monoculture	Maize grown in monoculture; one crop per-year in the first season; second season weedy fallow turned in with early land preparation at the end of rainy season
MRT	Maize-soybean rotation	Maize (1st season) and soybean (2nd season) in 1-year rotation; residues incorporated prior to planting in following season.
MGM	Mayze-soybean green manure rotation	Maize (1st season) and green manure (2nd season) in 1-year rotation. Legumes incorporated at maximum standing biomass levels in late rainy season.
NSC	Native savanna (control)	Managed traditionally by burning annually during the dry season; not grazed.
MAP	Maize-agropastoral rotation	Maize monocrop in year-1; *Panicum maximum* / *Glycine wightii / Arachis pintoi / Pueraria phaseoloides* pasture sown with rice in year-2; grazed to maintain legume content; rotated every 4 or 5 years depending on pasture composition.

Maize row-to-row and plant-to-plant distances were 80 and 15 cm, respectively. Tillage system NT in this study means that the plots were subjected to conventional tillage (CT) during the first 5-year period and were then sown with a direct drilling sowing machine, herein referred to as direct seeding (i.e. there was no intervention in the soil before planting). Conventional tillage involved use of disc harrows (3-4 passes) for soil preparation before each sowing period. Tillage system MT means that after 5 years of CT, one pass of chisel was done at soil depth of 30 cm during seedbed preparation where the distance between the chisel legs was 60 cm; a harrowing pass was done so as to have a better level of the soil for the sowing of maize and soybean, which were sown with direct-drilling machine (i.e. MT involved reduced harrowing intensity before planting). This means that after 5 years of being cultivated continuously with conventional tillage, the plots were sown with a direct-sowing machine (under both NT and MT), to determine if the cumulative effect of treatments had created suitable soil conditions for a no-till system. Plots under NT would represent the cumulative effect of treatments, while plots under MT would represent an additional improvement of the soil physical conditions.

First results indicate that agropastoral systems under MT generally presented higher H_2O-Po and NaOH-Po values than under NT while for $NaHCO_3$-Pi and $NaHCO_3$-Po the opposite trend was predominant (Figure 14). These observations suggest that tillage treatments differentially influenced biologically available soil P. Inorganic P fractions provided a clearer differentiation among treatments and higher values were generally found in MGM and MRT, while lower values were found in NSC and MAP. Nevertheless, better management options in P cycling likely include those treatments where most of the P is stored in organic form. Under highly weathered and strongly P-sorbing Oxisols NSC and MAP may provide a better protection of P from loss through fixation, as P flowing through inorganic pools is easily fixed as compared to P in organic pools. This confirms our earlier findings indicating that, in highly weathered and P-deficient tropical soils, P availability for plant growth may depend more on biologically mediated organic P turnover processes than on the release of adsorbed inorganic P.

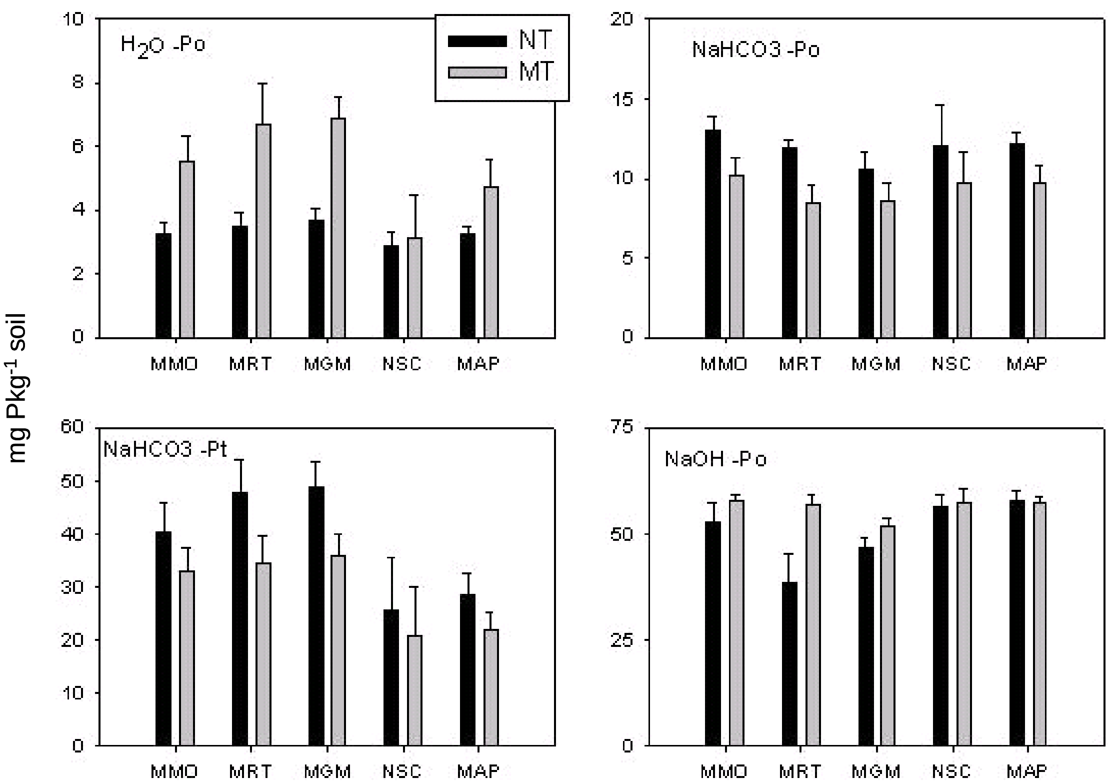

Figure 14. Effect of agropastoral treatments on soil P-fractions of different agropastoral systems. Error bars refer to standard errors of the difference in means.

Output target 2007

➢ ***Land use intensity impact on BGBD evaluated in seven tropical countries participating in the BGBD project***

Published work

Giller, K.E., Bignell, D.E., Lavelle, P., Swift, M.J., Barrios, E., Moreira, F., van Noordwijk, M., Barois, I., Karanja, N., and Huising, J. (2005). Soil biodiversity in rapidly changing tropical landscapes: scaling down and scaling up. In Biological Diversity and Function in Soils (eds M.B. Usher, R. Bardgett & D.W. Hopkins), pp. 295-318. Cambridge University Press, Cambridge.

Abstract:

1. Habitat modification and fragmentation of remaining pristine areas in the tropics is occurring at a speed that threatens to compromise any serious attempt to assess their value in the biosphere, and catalogue their true biological diversity.
2. Knowledge about the functional significance of soil biodiversity has been strongly influenced by emphasis on temperate climates and by focusing on particular processes of significance to high-input, intensive agriculture. We do not know how robust our methodologies and our concepts are when applied to low-input systems.
3. Links between diversity and function are clearer for functions that are relatively specific, such as the roles of ecosystem engineers, or specific nutrient transformations compared with generalist functions, such as decomposition, micrograzing, predation and antibiosis.
4. Substantial redundancy exists in relation to general functions that could be important for functional stability.
5. When considering the legume-rhizobium symbiosis as a specific case, rhizobial diversity based on molecular phylogeny is only weakly correlated with specific functions such as the ability to form nodules (infectiveness), to fix N_2 (effectiveness) and to survive in the soil (adaptation).
6. Major challenges for the future include developing tools for managing soil biodiversity through manipulation of above-ground vegetation and soil amendments, and understanding the effects of scale to design land use systems for optimal future conservation of the biodiversity of tropical soils.

Towards the end of the year 2004 two of the BGBD reviews were published. The BGBD review of the Kenyan BGBD team was published as a special issue of the **Journal of Tropical Microbiology (Volume 3. Number 1), A Special Issue with Selected Topics on Below-ground Biodiversity in Kenya**”. This publication was already reported on in the reported already in the 2004 annual report. The other publication was from the BGBD project Indonesia, though officially published still in 2004, it was not available until 2005 and was therefore not included in the annual report of 2004.

Susilo F.X., Abdul Gafur, MuhajirUtomo, Rusdi Evizal, Sri Murwani and I Gede Swibawa (Eds) (2004) Conservation and Sustainable Management of Below-Ground Biodiversity in Indonesia, Universitas Lampung Bandar Lampung, Indonesia, p 145.

Abstract: The book gives a review of the studies and research done in Indonesia concerning below-ground biodiversity, its importance for agricultural productions and for provision of other ecosystem services. Eighteen contributions from the various authors cover a variety of topics, including the relevance of below-ground and above ground biodiversity, effect of long term conservation tillage and nitrogen fertilization on soil mesofauna and earthworms, the ecological significance of root architecture of drought resistant plants in improving diversity and services of below-ground organisms, apart from

reports on specific organisms, to give some examples. The BGBD review by the Indian team was published in 2005.

Ramakrishnan, P.S., K.G. Saxena, M.J. Swift, K.S. Rao and R.K. Maikhuri (Eds.) (2005) Soil Biodiversity, Ecological Processes and Landscape Management, Oxford & IBH publishing Co. Pvt. Ltd., New Delhi, India, p. 302.

Abstract: The contents are divided into four sections, section 1 (13 chapters) deals with Soil Biodiversity and Ecological Processes, giving the status of research in India on the various group of soil organisms and related processes. Studies indicate that the mega-diversity status of India is reflected swell in its diversity of earthworm species of which 85% are native to India. The high diversity and endemism is explained by the specific geological history of India that as a sub-continent has never submerged through is geological history and the large variety in ecological conditions. The Western Ghats, known as biodiversity hotspot illustrates that high above-ground diversity is translated into a high diversity of earthworms as well. Studies show that land conversion results in loss of endemic species that are not recovered through secondary succession. The conversion of land use is also associated with change in the functional guilds, with increase in epigeic species in agricultural ecosystems.

Castings produced by earthworms may reach up to 140 t/ha and these have generally favorable properties when compared to the soil digested by the earthworms. This is recognized by farmers, many of which are culturing earthworms and use the castings for soil amendments.

As for earthworm, India also exhibits a characteristic and highly divers species composition. The diversity of termite species is directly related to plant/tree diversity. The family of *Termitidae*, which comprises nearly 75% of the known species in the world, has a comparatively poor representation in India. The functional role of termites has not received as much attention as termites as harmful insects to crops, though the beneficial role of termites in providing ecosystem services can be considerable and harmful effects can be mitigated through proper management. Comprehensive contribution on VAM and LNB are also included, the first paper outlining strategies making use of VAM: one is through inoculation techniques and the other through management of indigenous VAM species through agricultural practices.

Section 2 (7 chapters) deals with experimental research related to direct and indirect management of soil biodiversity. One paper shows considerable success obtained with the use of termites for restoring degraded lands, reducing bulk density and increasing soil N and soil C, after introduction of termites using various feeding strategies.

Impressive results have been obtained with rhizobium inoculation techniques in India, with cases reporting up to a 69% increase in yield compared to control. It indicates the potential of this technique; however the results are very inconsistent. Reasons for this inconsistency are discussed and a strategy is suggested to develop cultivars that do not from nodules with native rhizobium as a remedy.

A number of chapters deal with soil organic matter management. One chapter reports rice-wheat systems that no longer respond to increased fertilizer input, which seem to correspond to the decline in OM concentration to very low levels. Solutions are found in integrated use of fertilizer and organic resources and the combination of organic resources like FYM and green manure, through which yields are achieved that cannot be reached with fertilizers alone.

Section 3 (4 Chapters) deals with soil biology and ecology from a landscape management perspective. Chapters describe fallow management under shifting cultivation ion the North-eastern India and with soil fertility management in the BGBD benchmark area in the Western Himalayas that depends on the OM resources being collected for the forest. The sustainability of the system is discussed.

Section 4 provides a synthesis of information arising from sections 1-3 and the process identifying gaps in knowledge and areas of future research and applications. With respect to the inventory of soil biota the synthesis chapter concludes that capacity building in the area of systematics of soil biodiversity deserves urgent attention. Molecular techniques are advocated to be applied to organisms such as bacteria and fungi where morphological taxonomy offers limited scope. As for the soil biodiversity in relation to ecosystem processes it is concluded that the relation between above ground disturbance regime and below–ground biodiversity is still little understood, since the knowledge on the effect of land use change on changes in soil biota is limited. Research is needed to determine thresholds; i.e. what is the minimum number of functional groups to ensure ecosystem resilience. In relation to the importance of soil biota for agricultural productivity it is argued that major benefits could be derived from management of soil biota is in synchronizing nutrient release with crop demand and in controlling pest and disease. The positive impacts of direct and indirect management know from a few experimental set-up needs to be evaluated for different types of agro-ecosystems, and impacts needs to be evaluated in terms of sustainability of higher crop yields in the long run and ecological functions of agro-ecosystems, and socio-cultural acceptability needs to be further evaluated.

In relation to land use and land cover change, the associated management practices, driving factors and ecological and socio-economic implications are know only for isolated pockets. Quantitative information on the impacts of the changes in soil biodiversity and ecosystem function is even scarcer. Spatio-temporal dynamics in above ground and below –biodiversity and their implications need to be studied over a hierarchy of spatial scale – from plot to landscape units of varied sizes and functions. Finally the strength of indigenous knowledge should be capitalized on more effectively, overcoming its weaknesses with appropriate scientific and institutional inputs as an effective way of approaching sustainable development in developing countries.

As already mentioned, all country teams presented mostly preliminary results from the inventory of BGBD during the annual meeting held in Manaus Brazil. The abstracts of the papers presented are included in the report of the annual meeting: **"Proceedings of the Annual meeting 2005, Volume I inventory of Below-ground biodiversity in eleven benchmark areas, within seven tropical countries" edited by E. J. Huising.**

Kerala Forest Research Institute/TSBF-CIAT (2005) Proceedings of the national workshop "conservation and sustainable management of below-ground biodiversity", 21 – 23 June 2005, KFRI, Peechi, Keralal, India, p 621.

Abstract: The workshop included three main sessions. The first session was on theoretical issues concerning belowground biodiversity and review of work done in India. The second session dealt with the various management options and strategies involving BGBD. There were contributions related to vermi-composting, the role of mycorrhizal fungi in maintaining productivity in rice in shifting cultivation systems and use of rhizobium inoculants amongst others. The third session dealt with results from the inventory of BGBD in the three sites that the BGBD project maintains in India, and included site characterization, agronomic practices, inventory of the various functions groups of soil organisms.

Completed work

Soil biodiversity, ecosystem services and land productivity

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Increases in land productivity in the past have largely resulted from the introduction of new crop varieties into farming systems on fertile soils with good supplies of water, fertilizer and pesticides. However, in many less fertile parts of the planet land productivity has actually been declining in the last decades. While high input agriculture has been one alternative to this address this problem, the usually low resource use efficiency of these agricultural systems often leads to high economic and environmental costs. Recent years have shown increasing interest in the development of productive farming systems with a high efficiency of internal resource use and thus lower input requirement and cost. In this context, the importance of soil biodiversity for the improvement of soil fertility and land productivity through biological processes becomes a key component of a strategy towards agricultural sustainability.

The majority of ecosystem processes in both natural and managed ecosystems depend on the soil resource as it not only houses a large proportion of the terrestrial biosphere but also provides the physical substrate for most human activities. Although soils have been widely studied and classified in terms of physical and chemical characteristics, knowledge of soil biodiversity and function is very limited. The role of soil organisms in high input agriculture has received little attention likely because natural and biologically mediated processes like those regulating soil structure, nutrient supply and pest and disease control have been largely replaced by human inputs (i.e. soil tillage, fertilizer and pesticide applications) that ultimately depend on non-renewable energy sources. In natural ecosystems, the internal regulation of function is largely a result of plant biodiversity through flows of energy, nutrients and information, but this form of control is increasingly lost through agricultural intensification. One of the challenges ahead consists on promoting agricultural systems in landscapes managed to sustain rural livelihoods while simultaneously protecting the environment as expressed in the Millenium Development Goals.

Agricultural landscapes hold a large proportion of the world's biodiversity but there is limited understanding about the relative contribution of each management type to conservation of biodiversity, maintenance of ecosystem functions and provision of ecosystem services. According to the Millennium Ecosystem Assessment, ecosystem services can be classified into those associated with the provision of goods (i.e. food, fibers, fresh water), those derived from benefits of regulation of ecosystem processes (i.e. climate regulation, disease control, detoxification), those that support life in the planet (i.e. soil formation, nutrient cycling, pollination) and those cultural services that are not associated with material benefits (i.e. recreation, aesthetic, symbolic).

Soil biodiversity can be considered by focusing on the groups of soil organisms that play major roles in ecosystem functioning through direct or indirect impacts on ecosystem services. Direct impacts are those where specific organisms like symbiotic microorganisms (i.e. rhizobium and mycorrhiza) or pest and diseases (i.e. white grubs and root rots) have a positive or negative effect on crop yield respectively. Indirect effects, on the other hand, include those provided by soil organisms participating in carbon and nutrient cycles (i.e. methanogens and nitrifiers), soil structure modification (i.e. earthworms, fungi and bacteria) and food web interactions (i.e. protozoa and nematodes as microregulators) that generate ecosystem services that ultimately have an impact on land productivity.

Increasing research efforts need to be made to address the challenge of gaining a predictive understanding on the linkages between soil biodiversity, ecosystem functioning and the provision of ecosystem services. Our current GEF funded project entitled 'Conservation and Sustainable Management of Below Ground Biodiversity' that involves research teams from Brazil, India, Indonesia, Ivory Coast, Kenya, Mexico and Uganda is a current effort in this direction that is also addressing the economic valuation of ecosystem services provided by soil biota.

Greater understanding is needed because the adoption of agricultural technologies that rest on the biological management of soil processes driven by soil organisms would greatly depend on identifying creative ways by which farmers "experience" the impacts made by organisms that are not visible to the naked eye by being too small or because they are underground. The 'low profile' of soil biota and associated functions in the provision of ecosystem services has likely been an important factor in their almost complete ignorance in biodiversity conservation and policy development. This problem is particularly critical in tropical areas that are supposed to be the global 'hot spots' of biodiversity in general and of soil biodiversity in particular. Curiously, it is in tropical areas where data and information is most limited.

Work in progress

Environmental and socio-economic characteristics of eleven benchmark areas for demonstration of sustainable management options for conservation of BGBD, E. J. Huising and P. Okoth (eds). Full papers submitted by the seven BGBD country teams are currently being reviewed for inclusion in two project publications. One publication will address the characterization of the benchmark area in terms of soils, land use and socio-economic characteristics. The publication will evaluate and compare land use and land cover change in eleven benchmark areas that each represent eco-regions of global importance, in terms of drivers for the conversion in land use and land cover and considering the threats these conversions pose to below-ground biodiversity.

Loss of below-ground biodiversity as consequence of land use intensification in forest margins of selected biologically highly diverse ecological regions, E.J. Huising *et al.* (Eds). Results of the inventory of belowground biodiversity in the eleven benchmark sites of the BGBD project will be compiled in this publication. The inventory includes a wide range of functional groups of soil organisms, ranging from macrofauna as soil engineers to pathogenic fungi. The change in BGBD will be evaluated against change in land use pattern. Full papers have been received from all country teams covering most of the functional groups. Reviews of the papers have almost been completed.

Characterization of soil macrofauna in the Quesungual agroforestry system of western Honduras
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Agricultural practices that promote increased diversity and abundance of soil macrofauna may improve soil quality and productivity, due to the influence of soil macrofauna on organic matter breakdown, nutrient cycling and soil structure. Southern Lempira department in Honduras is an environment where farmers could benefit greatly from such an increase in soil quality. The landscape is hilly, with steep slopes and shallow soils that are susceptible to erosion. The need for shorter fallow periods, a decrease in the use of slash-and-burn agriculture, and promotion by extension agents has resulted in the large-scale adoption of an agroforestry system known as the 'Quesungual System', based on slash-and-mulch of vegetation, rotation of maize, sorghum and beans and inclusion of diverse trees and shrubs within cropped fields.

This study presents research on the effects of four common land use types (secondary forest, recently cleared agroforestry fields, mature agroforestry fields and silvopastoral fields) in the Quesungual area on soil macrofauna abundance and community composition. The overall hypothesis of the research project is that the Quesungual agroforestry system, through its use of structurally and taxonomically diverse plant species, diverse organic matter inputs, and crop rotation is creating a spatially and temporally heterogeneous soil environment, which leads to multiple niches for soil macrofauna and allows for increased soil biota abundance and diversity.

In August and September of 2004, a set of representative Quesungual agroforestry farms of varying ages (less than two years of continuous cropping, and more than ten years of continuous cropping), silvopastoral farms and fallow sites were chosen. Three farms were included within each category. A transect of 90 metres with a random origin was set up to cover a representative area of the farm, and sampling points were located every ten metres along this transect. Soil macrofauna were sampled at each point using a 'soil monolith' of 25 x 25 x 30 cm, based on standard methodology endorsed by the TSBF. The sample was divided into four layers: litter, 0-10 cm, 10-20 cm and 20-30 cm. The litter and soil samples were hand sorted on site for invertebrates larger than 2 mm, which were preserved in 70% ethanol. In the laboratory, invertebrates were sorted to a broad taxonomic grouping, counted and weighed (a biomass correction factor was applied to preserved weight). In addition to soil macrofauna, at each sample point the tree and shrub component of the vegetation was also quantified. All trees and shrubs within a radius of 5 metres of the sample point were identified, noted as pruned or free-growing (referring to the form of the tree) and the diameter at breast height (1.3 m) recorded.

The four types of land use surveyed differ in the abundance and diversity of tree species. Mean tree densities in relatively new farms (2262 $\pm$ 227 ha^{-1}) were similar to those found in secondary forest (2274 $\pm$ 224 ha^{-1}), while tree density fell sharply in older farms (1053 $\pm$ 114 ha^{-1}) and further in silvopastoral farms (492 $\pm$ 60 ha^{-1}). A similar drop in species richness occurred along the same sequence, from 35.0 $\pm$ 6.4 species per transect in secondary forest, 25.7 $\pm$ 4.3 per transect in young Quesungual farms, to 13.3 $\pm$ 0.8 species in older Quesungual farms and 14.3 $\pm$ 1.8 species per transect in silvopastoral sites (Figure 15).

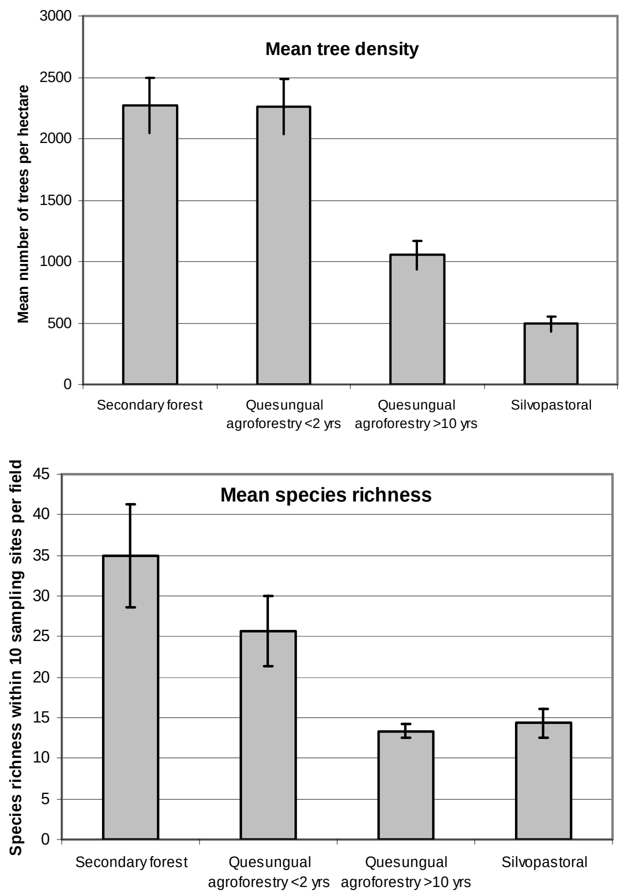

Figure 15. Mean tree density and species richness in each of four common types of fields related to the Quesungual system. Ten samples of tree density within circles of 5 metre radius were taken in three fields for each category. The species richness value is the average of the number of trees found within each of the transects for the three fields surveyed.

During the wet season of 2004, a total of 9673 invertebrates were sampled from the 12 sites with a net biomass of just over 167 grams. There was considerable variation both within and between sites, as shown in Table 13. Highest macrofauna density occurred in younger Quesungual farms, followed by silvopastoral farms, older Quesungual farms and finally fallow sites. Biomass was also highly variable, from a low of an average 2.12 ± 0.48 grams per m^2 at one of older Quesungual fields, to a high of 101.10 ± 24.05 grams per m^2 at another recently cleared field. Biomass tended to be greatest in Quesungual farms of less than two years of age, followed by older Quesungual farms, silvopastoral farms and finally fallow sites.

Table 13. Average abundance and biomass of invertebrates for each of the sites sampled.

Farm Type	Farm Site Name	Av. abundance per m^2	Av. biomass per m^2	N
Quesungual	Young Farm Site 1	814 ± 95	101.1 ± 24.0 g	10
< 2 years	Young Farm Site 2	1152 ± 323	9.1 ± 2.8 g	10
	Young Farm Site 3	2946 ± 916	15.4 ± 4.0 g	10
	All sites	**1637 + 359**	**41.9 ± 11.1 g**	30
Quesungual	Mature Farm Site 1	1586 ± 554	12.5 ± 3.3 g	10
>10 years	Mature Farm Site 2	1112 ± 246	48.7 ± 12.7 g	10
	Mature Farm Site 3	850 ± 355	2.1 ± 0.5 g	10
	All sites	**1182 ± 233**	**21.2 ± 5.6 g**	30
	Silvopastoral Site 1	1510 ± 710	7.3 ± 2.3 g	10
Silvopastoral	Silvopastoral Site 2	2333 ± 887	30.7 ± 7.2 g	10
	Silvopastoral Site 3	682 ± 175	5.3 ± 2.1 g	10
	All sites	**1508 ± 390**	**18.1 ± 3.3 g**	30
Fallow	Fallow Site 1	600 ± 219	13.2 ± 4.6 g	10
(Guamil or	Fallow Site 2	1214 ± 545	12.9 ± 4.2 g	10
2^o Forest)	Fallow Site 3	680 ± 116	9.6 ± 1.6 g	10
	All sites	831 + 199	11.9 + 2.1 g	30

There was also a high degree of variation in the composition of the macrofauna community at each site sampled. Overall, Isoptera (termites) were the most abundant group, making up 50.5% of invertebrates sampled. Hymenoptera (ants) were the second most abundant, at 21.5%, followed by Oligochaeta (earthworms) at 11.8%, Coleoptera (beetles) adults and larvae at 4.9%, and Myriapoda (millipedes and centipedes) at 4.8%. Earthworms in particular tended to be locally very abundant with a patchy distribution, with some sites recording over 400 individuals m^{-2} and others recording fewer than 20 m^{-2}.

The data shown in Figure 16 demonstrate how relative proportions of the major groups vary with land use. For the whole depth of soil and litter to 30 cm, of the three agricultural uses, young Quesungual farms had the highest abundance of most taxonomic groups apart from the social insects. Abundance of litter-dwelling myriapods was highest in secondary forest, and decreased under agricultural use. Conversely, Isoptera consistently increased in number with conversion to agriculture. Oligochaeta were more abundant in Quesungual fields than in either forest or pasture. At soil depths between 10 and 30 cm, the three agricultural uses showed very similar patterns of relative abundance for most groups, although these are notably different from those in secondary forest sites.

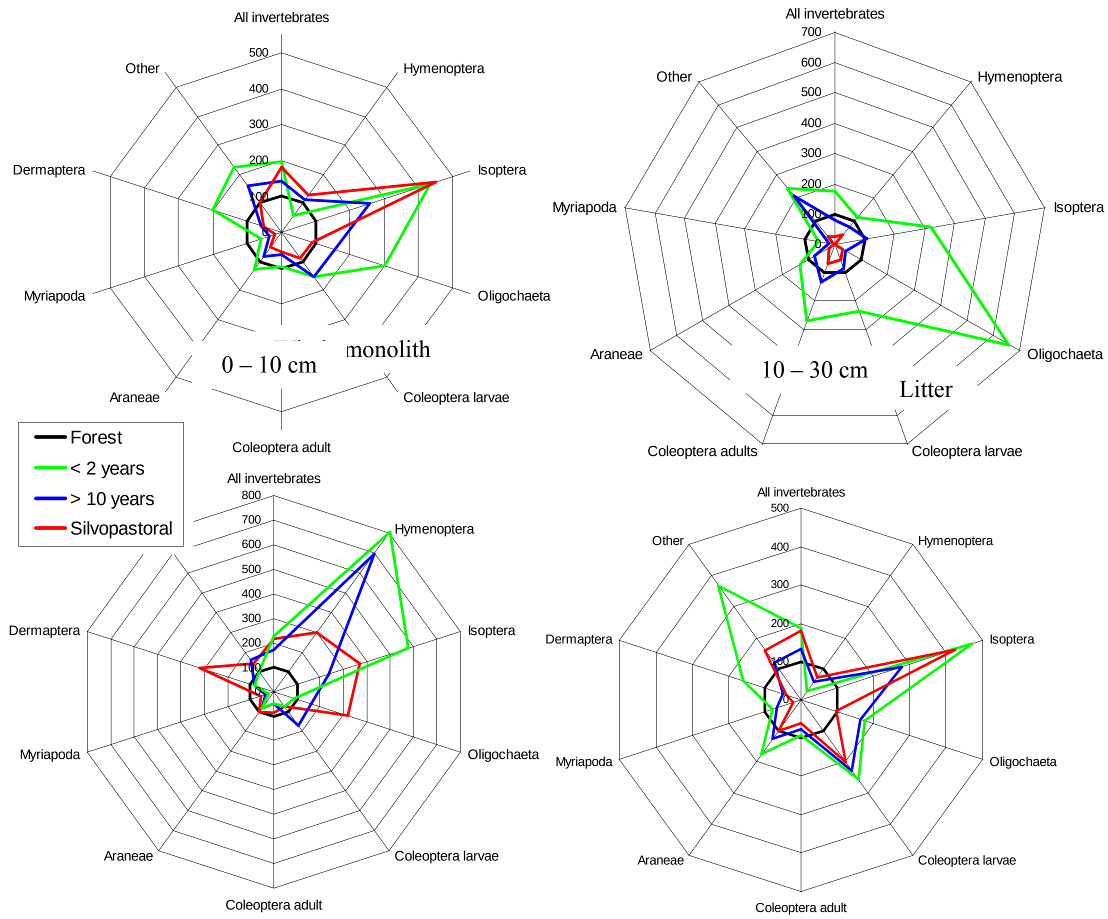

Figure 16. Relative abundance of the all invertebrates and the major groups at varying depths for the four land uses. Abundance in forest sites was taken as 100% and other sites compared to this.

A variety of biophysical factors are likely to influence the distribution of soil fauna, with the result that soil fauna communities are highly variable both within fields, between replicate fields, and between land use types. Despite the highly variable nature of the data, some observations can be made by way of comparing this system with other studied systems. Biomass was not highest, nor was density lowest, under pasture, as expected from previous studies. This may be due to the inclusion of trees within pasture fields, which may not have been present in such high numbers in pasture fields in other studies. It may also be due to the location of pasture fields within a mosaic landscape of agroforestry fields and forest, which may act as habitat refuges for invertebrate populations.

Different ecological and taxonomic groups of soil fauna can be expected to respond in different ways to changes in environmental conditions. Myriapods are consistently reduced in the litter and at all soil depths under agricultural land use, while termites consistently increased in abundance, particularly in agroforestry systems. Ants greatly increased their number in agricultural uses compared to forests in the upper soil, while differences were not as great at other depths. Other studies have also found that myriapod density is significantly affected by land use, and that social insects such as ants and termites increase with cultivation. Both changes are likely to be related to changes in quantity and diversity of organic matter inputs and habitat availability.

The large proportions of individuals present at soil depths between 10 and 30 cm for all land uses was higher than expected, and seems to have been a result of high levels of ant and termite activity at depth in many farms. The dominance of earthworms in the 0-10 cm layer, particularly in pasture sites, may indicate high soil turnover and availability of organic matter at this depth. The decrease in the proportion of litter invertebrates along a gradient from secondary forest through agroforestry and pasture may reflect migration by litter fauna to greater depths as physical protection from environmental fluctuations decreases. The similarities amongst agricultural land uses in the relative proportions of individuals at depths of 10 to 30 cm suggest that community structure and availability of food resources is fairly similar amongst all agricultural uses at greater soil depths.

The greatest challenge facing this study, and the most important in terms of local management of soil biological resources, remains to translate the results of this study and its companion studies into a set of management guidelines that can be used by local farmers to manage soil macrofauna abundance and diversity within their fields, with the goal of improving soil quality and soil fertility.

Local knowledge, soil macrofauna and farm management in the Quesungual agroforestry system of western Honduras

N. Pauli [1,2,3,*], E. Barrios[2], T. Oberthür[3] and A. Conacher[1]

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As part of a broader research program on the functioning of the Quesungual agroforestry system of western Honduras, a study was undertaken of local knowledge of soil fauna and the environmental influences on their distribution and abundance. Little research has been undertaken on local knowledge of soil animals, even though soil fauna can make an important contribution to soil quality through their effects on soil structure and organic matter breakdown. The objectives for this study were two fold: 1) to gain an understanding of the depth of farmers' knowledge of soil fauna, their ecological roles and influences on their distribution; and 2) to better understand local perceptions of soil fauna, so that any management recommendations will be directly applicable.

The local knowledge of farmers practicing Quesungual agroforestry was investigated using semi-structured interviews with 20 farmers in the zone. Interviews were conducted in a conversational manner, and often included a guided tour of the farmer's parcel of land. The objective of the interviews was to understand the values that each farmer attaches to soil fauna and trees as indicators of the quality of the soil, and to find out to what extent farmers recognise changes in the abundance and diversity of soil fauna within their farms (as influenced by factors such as topography, soil, trees), and throughout the year. A further aim was to gain information on farm management practices that could be affecting the abundance of soil fauna within farms, such as the use of fertilizer, pesticides and tree selection.

Earthworms were the most commonly nominated type of soil invertebrate, and were generally regarded as an organism that was beneficial to farm activities. However, all other nominated organisms were generally regarded as having harmful effects on farm activities (see Figure 17). Individual farmers often noted that a particular invertebrate could have both harmful and beneficial effects, particularly in the case of ants. Leaf-cutter ants can inflict substantial crop damage, but at the same time farmers recognise that the discarded material that surrounds the exits to their nests is nutrient-enriched, and often collect this material to aid in the fertilization of high-value crops such as tomatoes.

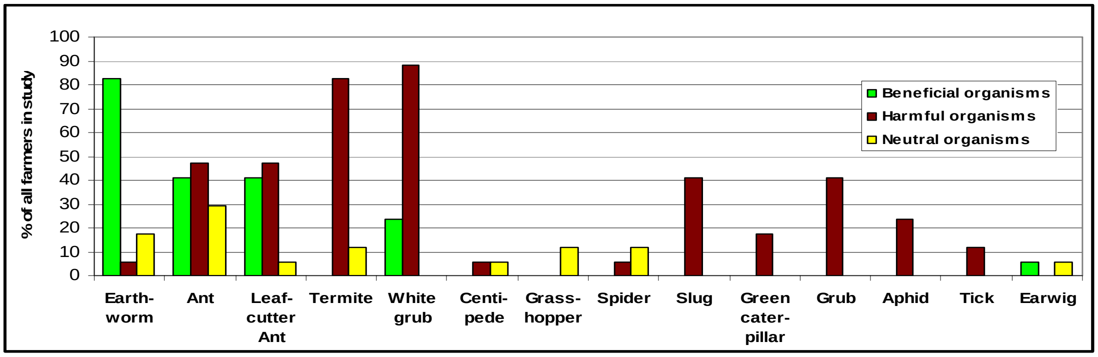

Figure 17. Farmer perceptions of soil invertebrates, Candelaria region, Honduras
Note that not all farmers nominated every type of invertebrate listed here.

Farmers recognized that many different environmental factors could influence the spatial and temporal distribution of soil fauna (see Figure 18). Over 90% of farmers recognized a difference in soil fauna abundance between the dry and wet seasons. Other commonly noted factors were soil fertility status, topographic position in the landscape and type of land use (i.e., pasture, maize crops, fallow). Less commonly noted factors included the presence of trees, shade, surface mulch and animal manure.

Farmers had substantial knowledge of soil fauna diversity and activity in their farms, as well as an understanding of spatial and temporal changes in soil fertility. Factors that farmers considered as important influences on soil fauna were often those that have an influence at broad spatial or temporal scales (season, topography, soil type), while those with a less important influence take effect at a more restricted scale (trees, shade, green manure, animal manure). This finding allows us to construct a hierarchy of environmental factors that have influence at increasingly more detailed scales, which can then be compared to the results of scientific investigations on soil fauna distribution to examine the similarities and differences between the two knowledge systems.

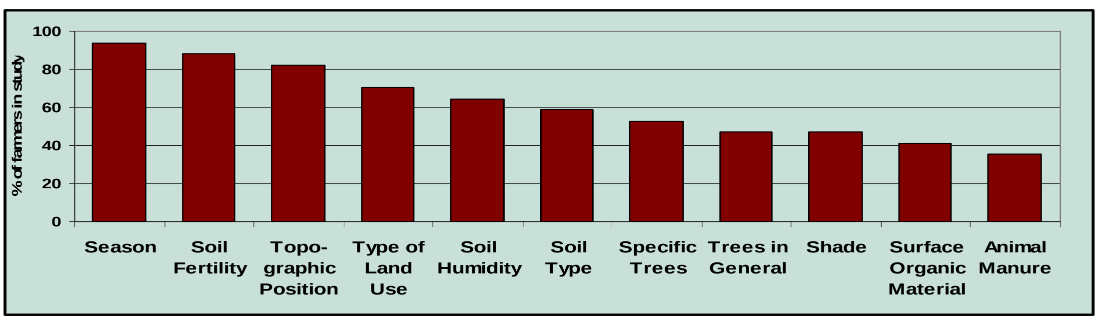

Figure 18. Farmer perception of factors affecting general soil macrofauna distribution.

Similar results were gained from a participatory mapping exercise that was undertaken with a small number of farmers from the region. During a tour of the farm plot, farmers would identify broad zones that were generally good for crop growth or were less fertile due to “static” factors such as soil texture, soil type, aspect or topography, but within each zone, specific areas were identified that for “dynamic” reasons had higher or lower crop yields in that particular growing season, such as high shade cover, high leaf-cutter ant activity or fertilizer shortage.

With regard to management, it is important to note that aside from earthworms, soil invertebrates were generally perceived as prejudicial to farm activities. For example termites, which were highly abundant in farmers’ fields, were generally perceived as harmful because they can damage valuable timber and sometimes feed on ears of corn during the drying process. Small ants often carry away newly planted corn and sorghum seeds but do little harm to established plants. For these reasons, farmers are unlikely to respond positively to management recommendations to augment populations of these animals in their field, but probably would respond positively to measures aimed at increasing earthworm populations.

Spatial dynamics of soil macrofauna: the importance of scale

N. Pauli [1,2,3,*], E. Barrios[2], T. Oberthür[3], A. Conacher[1] and E. Garcia[2]

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In the soil environment, there are many potential abiotic and biotic factors that could influence the spatial distribution of organisms. However, until recently, spatial variation in soil fauna populations was often regarded as random noise in analyses. There has been a flurry of recent research on the spatial distribution of soil fauna, for two main reasons. First, an understanding of the spatial and temporal distribution of soil macrofauna is considered to be important in order to "scale-up" the results of plot-based studies to larger scales, such as catchments, regions and ecosystems. A second area of research focuses around the notion that understanding the spatial and temporal variability of soil macrofauna populations at different scales may be the key to understanding the ecological function of high soil biodiversity, and the interaction between environmental variables and soil fauna.

Agroforestry systems, with their use of diverse crops and over-story trees, present an environment that is highly spatially and temporally dynamic. If changes in above-ground biological resources are important to below-ground biological resources, we should expect that such diversity of vegetation in space and time is reflected in the distribution and abundance of soil macrofauna. This could in turn have important effects on ecosystem function, by creating alternating areas of high and low faunal activity, with resultant effects on organic matter breakdown, nutrient cycling and soil structure.

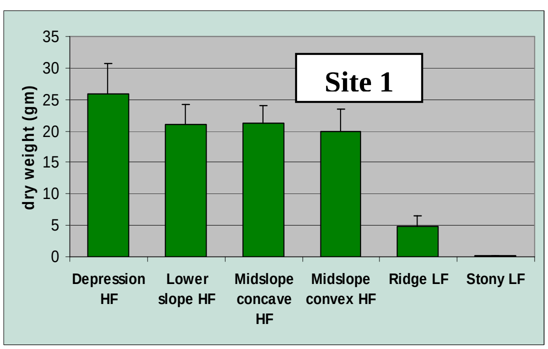
The "Quesungual" agroforestry system of southern Honduras presents an opportunity for studying the effects of included trees on soil macrofauna dynamics in time and space. Pilot surveys of macrofauna distribution in the region indicated that at a broad scale, soil macrofauna communities are highly variable, and variables such as land use, soil texture or overall vegetation cover were not good predictors of soil fauna abundance. The objective of the current study was twofold: 1) To identify an appropriate scale at which changes in soil macrofauna abundance can be related to environmental variables, and 2) To determine whether trees included within fields exert an influence on soil macrofauna distribution. The eventual goal is to use these results to develop management recommendations for local farmers, so that they may incorporate the beneficial soil macrofauna within their fields.

Since preliminary results indicated that soil macrofauna communities were highly variable within and between farms, it was necessary to stratify the sampling design to take account of variation in broad-scale factors such as topography and soil texture. These factors can have a significant effect on soil macrofauna, principally because of their influence on soil moisture. Two representative farms were chosen, one with a diverse, abundant macrofauna population (Site 1), and one with a very sparse macrofauna population (Site 2). The farms shared similar altitude, geographic location, management characteristics, geology and broad soil type. The farms were stratified using a two stage process. To begin, a map of local soil types and quality was made based on the farmer's knowledge during a participatory mapping exercise. Second, the soil type / soil quality classes were further divided according to topography (for example, upper-, mid- or lower-slope. The resultant maps contained six distinct zones in Site 1 and five in Site 2. In each of the zones, 20 sample points were located where detailed sampling of biological variables (dry weight of fresh earthworm casts, ant nest density, litter cover) was taken. Single factor ANOVA was used to test differences between the groups. Soil samples to test texture, organic matter content and aggregate stability were taken from 30% of these sites. Further, low-altitude digital aerial photographs will be used to characterise the density and distribution of overstorey trees within each of the zones.

A second set of data was taken at a more detailed scale, specifically to determine the influence of tree location on macrofauna. In each farm, a regular grid of more than 100 sampling points was located in one of the topography / soil class zones. The spacing of the grid points at 2 metres was determined based on the results of a pilot study undertaken 12 months previously. At each point, data was taken on pruned tree abundance, dimensions of free-growing trees, dry weight of fresh earthworm casts, abundance of ant nests, and litter cover. Although statistical analysis is still to be undertaken on this data, there are some strong evident trends which can be presented here in graphic form.

Both farmers identified areas of high and low soil quality within their farm, which were principally related to local classification of soil type. Areas with dark-coloured, loamy soil were generally considered as highly fertile, while areas with yellow- or red-coloured sandy or high clay-content soils were generally considered less fertile, as were areas presenting a high proportion of stones or a hardpan layer below the surface. Topographic position was generally not considered explicitly in farmers' classifications.

Preliminary results of sampling of indicators of soil biological activity lend support to farmers' perceptions. In the fertile Site 1, evidence of earthworm activity was significantly more abundant ($p<0.001$) in zones classified as fertile by the farmer than in less fertile areas with shallow, stony soils or exposed locations (Figure 19). However, litter cover was similar throughout the whole farm. In the lower fertility Site 2, a similar pattern was observed for earthworm casts, with fertile zones recording significantly more activity ($p=0.01$) than low fertility zones (Figure 19). In this farm, litter cover was significantly greater in fertile areas than low fertility areas ($p<0.001$).



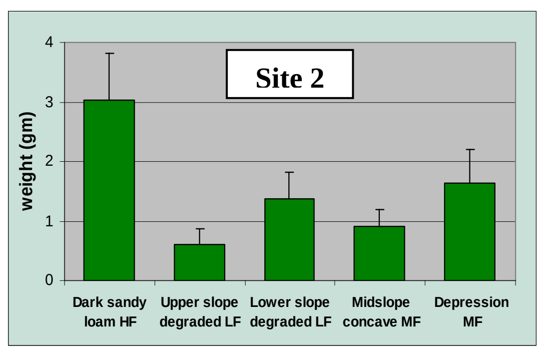


Figure 19: Dry weight of earthworm casts, Sites 1 and 2. HF = High fertility zone, LF = Low fertility, MF = Medium fertility.

Some very interesting results were obtained from the detailed grid survey. In the more fertile Site 1, pruned tree distribution was relatively even over the whole grid area, and litter cover and earthworm casting activity also appear to be relatively evenly distributed. (Figure 20). Ant activity was very low in this farm, while earthworm surface activity was very high. In the less fertile Site 2, pruned trees and free-growing trees were distributed irregularly, with areas containing clumps of trees and some areas containing no trees (Figure 21). There appear to be corresponding changes in litter cover, earthworm activity and ant nest activity. Although relatively even throughout the quadrat, the areas with the lowest litter cover occurred in areas with no tree cover. Earthworm activity appeared to be concentrated beneath pruned trees and tall trees. Ant activity displayed the opposite trend, with nest sites located principally in areas with no trees or low tree abundance.

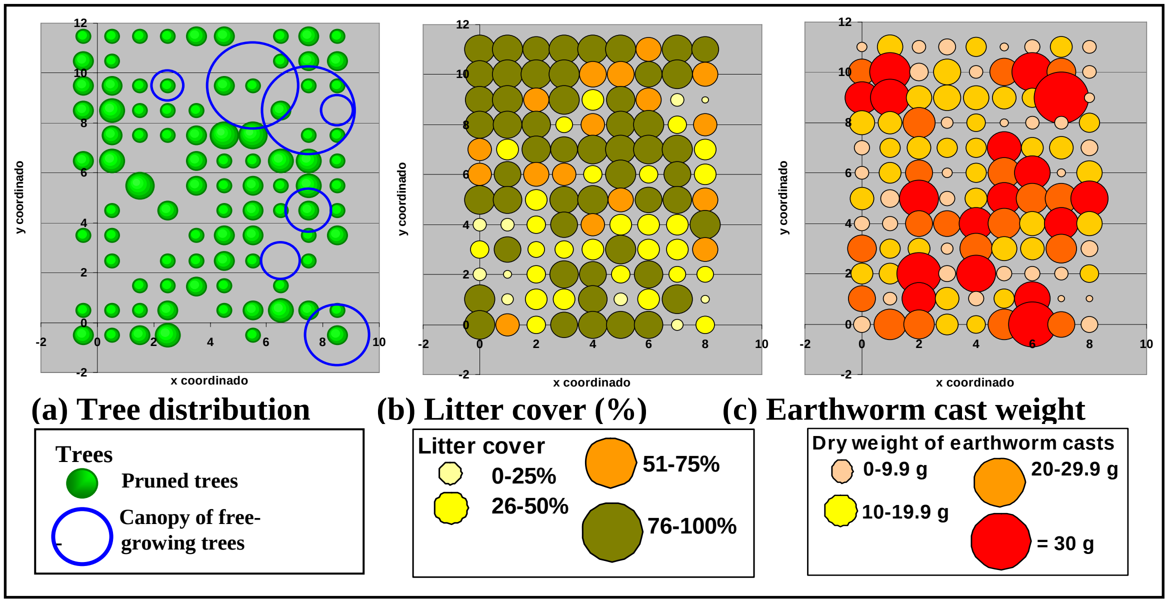


Figure 20. Spatial distribution of selected variables in Site 1 (High soil fertility). Pruned trees are relatively evenly distributed across the plot, with a corresponding even distribution of litter material, much of which is derived from tree prunings. Earthworm cast distribution is also relatively even, although it appears areas with more pruned or large trees tend to have slightly more cast material.

The results of the stratified survey clearly show that differences in topography and soil type within farms affect the activity of soil macrofauna and in some cases, the distribution of farm resources such as litter cover, which protects soils on the steep slopes from soil erosion. At a broad scale, soil macrofauna activity is dependent on soil type (soil texture) and topographic influence. However, at this level of resolution, we cannot determine the more localised effects of trees on below-ground biological resources.

At a more detailed level, once differences in topography and soil type are removed, it is possible to see the influence of trees on soil fauna activity and litter cover. Although results are still preliminary, it seems that the pattern of distribution of trees affects the distribution of other resources. When tree distribution is clumped, we can expect to see a more aggregated distribution of litter cover and macrofauna distribution. However, when trees are distributed more regularly or at higher densities, there is a corresponding more regular distribution of litter cover and macrofauna activity. It appears that pruned trees have similar effects on soil fauna distribution as large trees; thus, farmers do not have to increase the density of large trees (which compete with crops for sunlight, water and nutrients) in order to increase litter cover and soil fauna activity. This research has important implications for farm management, as it shows that farmers can manage litter cover and macrofauna activity by manipulating pruned tree density and distribution.

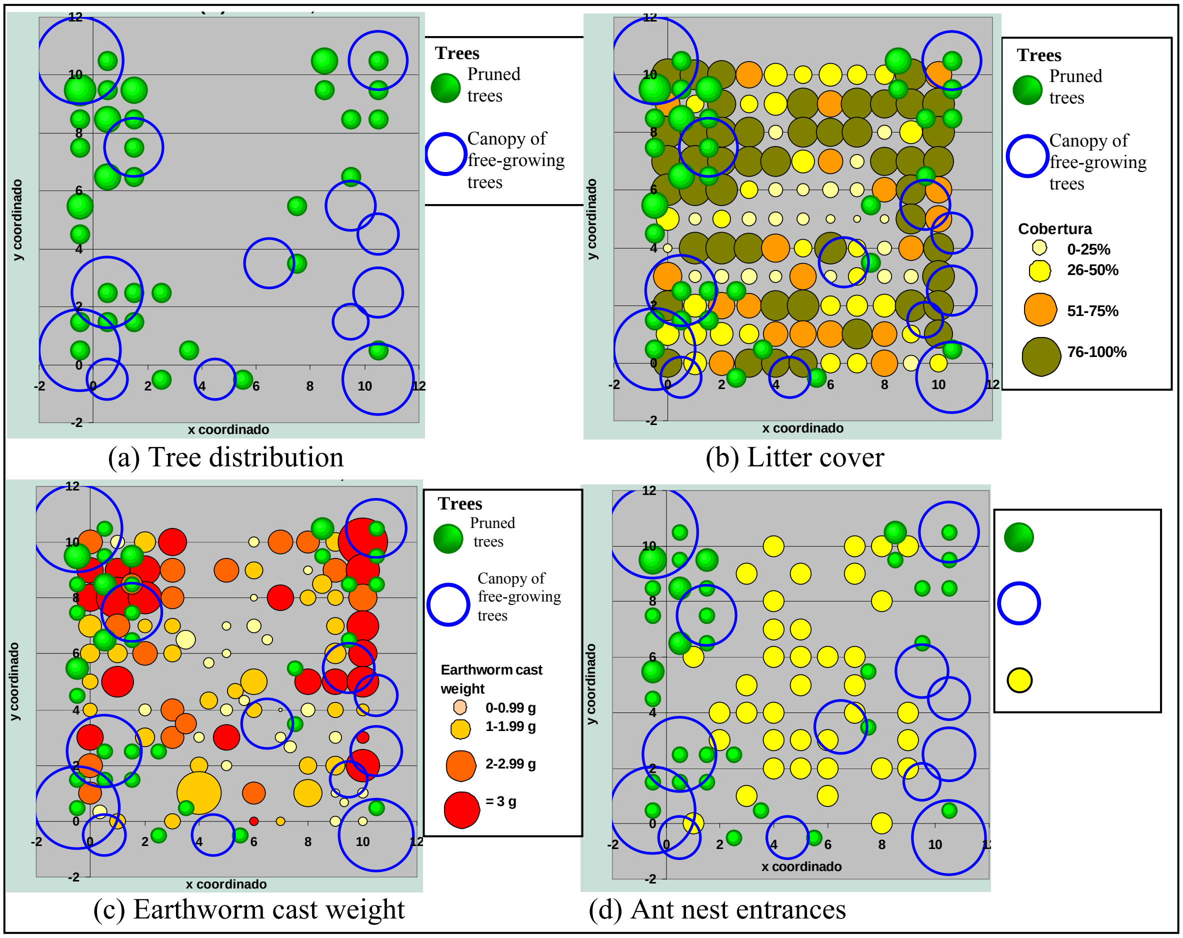


Figure 21. Spatial distribution of selected variables in Site 1 (Low soil fertility). Pruned and free-growing trees display an aggregated pattern of distribution. This aggregation seems to have affected the distribution of earthworm and ant activity, with more earthworm activity beneath trees, and higher ant nest concentrations away from trees. Litter cover also shows a moderate association with tree distribution.

Output target 2007

- ***At least two indicators of soil quality used for farmer's decision making in hillsides agroecosystem***

Completed work

Indicators of Soil Quality: A South-South development of a methodological guide for linking local and technical knowledge

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There is increasing evidence that land degradation induced by agriculture has been promoting a gradual shift away from the high input agriculture paradigm, based on overcoming soil constraints with fertilizers, lime, biocides and tillage to fit plant requirements, towards a paradigm with greater reliance on soil biological processes. This more ecological approach is based on adapting germplasm to adverse conditions, enhancing the biological activity of the soil and optimizing nutrient cycling to minimize external inputs and maximize the efficiency of their use. More recent conceptual developments have led to the emergence of the Integrated Soil Fertility Management (ISFM) paradigm. ISFM is a holistic approach to soil fertility research that embraces the full range of driving factors and consequences - biological, physical, chemical, social, economic and political, of soil degradation. There is a strong emphasis in ISFM research on understanding and seeking to manage the processes that enable change.

Paradigm shifts may allow us to see and understand the world in new ways, but unless their implications are internalized and accepted by farmers they will not yield beneficial impacts through adoption of improved soil management options and healthier landscapes. The limited adoption of new technologies and new cropping systems is now being recognized as closely related to the failure to take into account the local experience and needs of farmers. The limited understanding of underlying causes of ecological change induced by land management creates uncertainties that may also prevent adoption because of perceived high risks. Uncertainty, however, can be reduced by relevant scientific knowledge that integrates local knowledge.

The complementary nature of indigenous and technical knowledge in agriculture has been increasingly acknowledged. While experimental research provides information that can help farmers make better decisions, scientific approaches alone are insufficient for addressing the sustainable management of agroecosystems. The limited success of top-down approaches to management of tropical soils that have excluded farmer insights, has led to an increased recognition that local knowledge is a key resource for the sustainable management of tropical soils.

Farmer's knowledge and scientific knowledge share a number of common 'core' concepts but each knowledge system has gaps that in many cases can be complemented by each other. It is thus argued that research efforts should further explore a balance between scientific precision and local relevance resulting in a "hybrid" knowledge base. It is this expanded 'shared' hybrid knowledge that we are envisioning as the goal of using our methodological approach. The generation of "hybrid" knowledge reflects an effort to understand land management in the context of many forces interacting within a dynamic rural livelihood context.

For farmers and researchers to develop acceptable, cost-effective strategies for improved soil management a common language is required to integrate local and technical knowledge about soils and their management. To facilitate this integration process and make it repeatable, a methodological guide was developed and used in Latin America and the Caribbean. In a South-South exchange of methodology development the guide was further adapted for use in eastern Africa. This guide focuses on identifying and classifying local indicators of soil quality (LISQ) related to permanent and modifiable soil properties, and proposes simple methods that can be used by farmers, extension officers, NGO's, technicians, researchers and educators. This example of South-South collaboration through the transfer of concepts and methodological approaches from Latin America to east Africa has had different implications to different types of partners. Impacts where analyzed in: a) the formal education sector (Makerere University – Uganda), b) a regional research organization (African Highlands Initiative, AHI - Tanzania) and c) a global NGO (CARE-Kenya - Kenya).

This methodological approach is based on the belief that for sustainable soil management to become a reality farming communities require improved capacities to better understand and manage agroecosystem function. Improved capacities of technical officers (extension agents, NGO's, researchers) to understand the strengths and weaknesses of existing local knowledge is also part of the methodology. As limited communication between the technical officers and the local farm community is often a major constraint to capacity building, the methodology deals with ways of jointly generating a common knowledge that is well understood (and "owned") by both interest groups.

Technical indicators of soil quality (TISQ) usually include basic parameters, such as, bulk density, pH, effective rooting depth, water content, soil temperature, total C and electrical conductivity. Local indicators of soil quality (LISQ) are often more variable and include crop yield and vigor, soil color, soil texture and structure, and the presence / absence or abundance of local plant and soil invertebrate species. It should be noted that many LISQ integrate multiple aspects of soil quality in a single indicator and they are much more user friendly than complicated laboratory tests.

Selecting a suitable set of indicators of soil quality (ISQ) is the first step in the conceptual model describing the development of local soil quality monitoring systems (SQMS) in Figure 22. These ISQs are identified from the local and technical knowledge systems and critical levels would need to be defined in order to determine the main soil management limitations of the agricultural system under study. The predominant use of local and/or technical parameters, now part of a common "hybrid" knowledge, varies according to the monitoring objectives; e.g.: greater reliance on local indicators if the users will be primarily farmers, clear linkages between local and technical indicators for extension agents, or integrative technical indicators for policy makers. Attention should also be paid to the inclusion of indicators that can be used while progressively increasing the scale at which results are applied (e.g. from plot to field and farm level, up to watershed, region and nation level). Some examples of such indicators might be crop yield and yield trends, land cover, land use intensity and nutrient balances. More recently, the use of resource and nutrient flows at farm scale to assess land use sustainability and local variation usually missed in studies at higher levels of aggregation (i.e. region, country) has also been proposed by some researchers.

This phase would be followed by the definition of guidelines for the SQMS along with information on interpretation of results. User feedback is very important during this stage because it would contribute to the robustness of the SQMS and thereby should build the grounds for its acceptance. Once the SQMS is fully accepted by users, it can become a Decision Support System (DSS) for management of the soil resource at the farm, village and landscape levels.

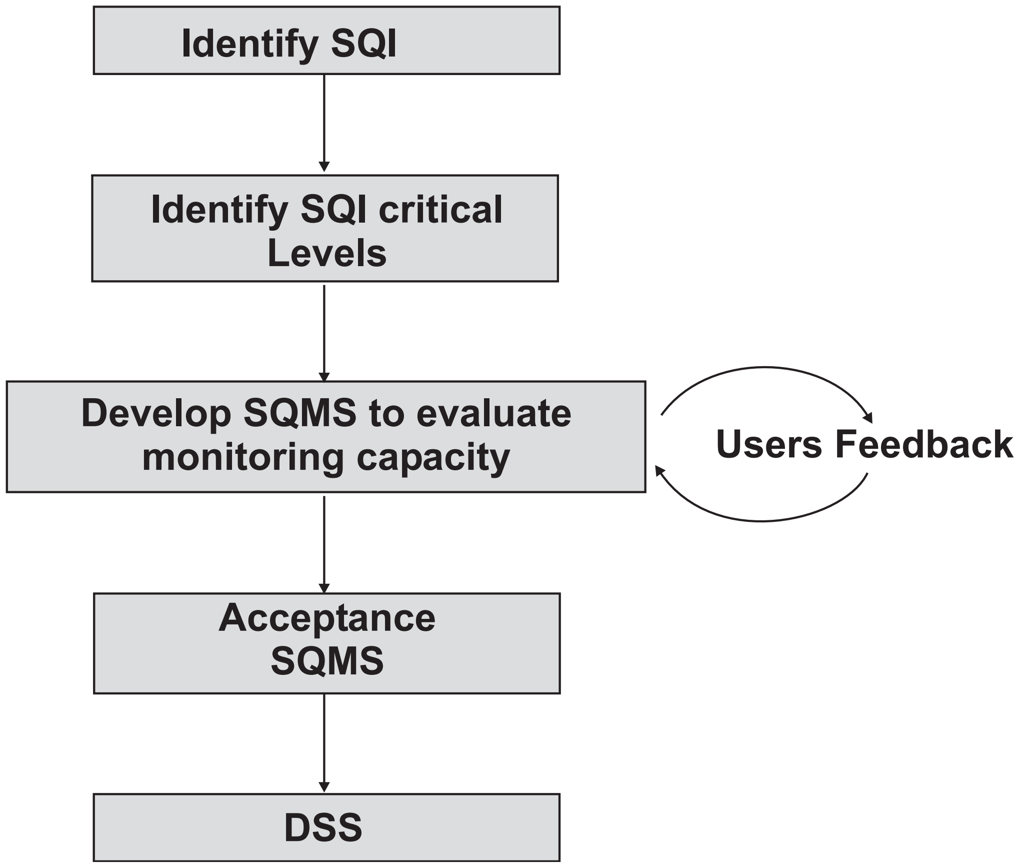

Figure 22. Conceptual model describing process leading to the development of Soil Quality Monitoring Systems

Farmers need early warning indicators of soil quality and monitoring tools to guide soil management because the cost of preventing soil degradation is several times less than costs of remedial actions. Many technical solutions to soil degradation exist but are not adopted because they are developed without the participation of the land user or do not build on local knowledge about soil management. The methodology described here has generated positive impacts on the local knowledge base by providing a way for this tacit knowledge to be widely understood, assessed and utilized, and to be integrated with technical solutions. In addition, local communities have been empowered by the joint ownership of the "hybrid" knowledge base constructed during this process. Action plans developed by local actors through consensus building and new insights derived from the training exercise become the means by which profitable and resource conserving land management are locally promoted and widely adopted.

The South-South cross-fertilization experience provided a unique opportunity to test the hypothesis of convergent evolution, borrowed from natural sciences, in the context of local knowledge systems. The concept of convergent evolution is related to the capacity of natural populations of organisms from distant locations to evolve in similar ways if faced with similar adaptive pressures from their surrounding environment. Our studies of local knowledge systems held by farmer communities in Latin America and Africa suggest that using this concept may be possible for soil quality indicators. Farmer communities studied in Africa (East African Highlands) and Latin America (Central American and Andean hillsides) came from comparable environmental contexts where soil texture (workability), soil depth, soil organic matter (soil color), slope and other common factors played an important role in farmer decision making.

Probably, the most compelling example is associated with the native plants frequently used by farmers as biological indicators of soil quality. In Table 14 we compare rankings of indicator plants conducted by Latin American hillside farmers to characterize quality of agricultural soils with those used by African highland farmers. It is remarkable that quite often the same ubiquitous plants are ranked similarly by farmers in Latin America and Africa as indicators of soil quality (i.e. *Pteridium arachnoideum*, *Bidens pilosa* and *Ageratum conyzoides*) but also that species of the same genus are found in both continents indicating a similar soil quality condition (e.g. *Commelina difusa* and *Commelina africana*). This example also suggests the potential to find useful information at the botanical genus or family level and this would considerably facilitate the wider use of local plants as indicators of soil quality.

Table 14. Native plants as local indicators of soil quality in Latin America and Africa.

	Latin America		**Soil Quality**		**Africa**	
Local name	**Scientific name**	**Botanical family**		**Local name**	**Scientific name**	**Botanical family**
Helecho marranero	*Pteridium arachnoideum*	Pteridaceae	Poor	Mashiu	*Pteridium arachnoideum*	Pteridaceae
Mangaguasca	*Braccharis trinervis*	Compositae	Poor	Ma-shuuti	*Philippia usambaresnsis*	Ericaceae
Escoba Lanosa	*Andropogon bicornis*	Gramineae	Poor	Digitaria	*Digitaria sp.*	Gramineae
Siempre Viva	*Commelina difusa*	Commelinaceae	Fertile	Olaiteteyai	*Commelina africana*	Commelinaceae
Papunga	*Bidens pilosa*	Compositae	Fertile	Enderepenyi	*Bidens pilosa*	Compositae
Hierba de chivo	*Ageratum conyzoides*	Compositae	Fertile	Olmalive	*Ageratum conyzoides*	Compositae

Farmers usually manage their soils for short-term maximization of benefits rather than with a longer term perspective of soil resource use optimization. This means that they miss out on the longer-term benefits of ecosystem services. It is thus essential that farmers and other stakeholders in land management, develop greater awareness about the livelihood and income generating opportunities that can be derived from the services provided by natural and agricultural ecosystems like provision of clean water, reduction in soil erosion, increased C sequestration and reduction of greenhouse gas emissions. However, in order for profits to be made from ecosystem services a major change in sustainable natural resource management needs to occur based on much wider adoption of improved land management options.

Work in progress

Assessment of farmers' perceptions of soil quality indicators for crop production within smallholder farming systems in the central highlands of Kenya

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[1]*Kenyatta University, Kenya;* [2]*TSBF-CIAT, Nairobi , Kenya*

'Soil quality' and 'soil health' are used interchangeably refer to the soils'capacity to support agro-ecosystem function, environmental health, and crop growth and productivity. Due to continuous and intensive cultivation, farmers have experienced declining crop yield over time raising both scientific, and farmer environmental concerns over soil quality. A study was conducted to determine farmers' perceptions of soil quality and common soil management practices that influenced soil fertility within farmers' fields in Chuka and Gachoka divisions, Kenya. Indigenous knowledge and environmental data was collected in face to face interviews and field assessments respectively. Soils were characterized by farmers after which they were sampled at surface depth (0–20 cm) for subsequent physical and chemical analyses, to determine differences within farmers' soil quality categories. Indicators for distinguishing productive and non-productive fields included crop yield and performance, soil colour and soil texture. A total of 18 indicator weed species were used to characterise soil quality. There were significant differences among soil fertility categories, using parametric techniques (ANOVA) for key soil properties ($p<0.005$), implying that there was a qualitative difference in the soils that were characterized as different by farmers. Fertile soils had significantly higher pH, Total organic carbon and exchangeable cations, with available-N being significantly different in Gachoka. Soil fertility and crop management practices that were investigated indicated that farmers understood and consequently utilized spatial heterogeneity and temporal variability in soil quality status within their farms as a resource to maintain or enhance agricultural productivity.

Strengthening "Folk Ecology": Applying community-based learning and communication strategies to improve soil fertility and livelihoods in western Kenya

J. J. Ramisch[1], M.T. Misik[2], I. Ekise[1], R. Verma[1] and J. B. Mukalama[1]

[1]TSBF-CIAT, Nairobi, Kenya; [2]Wageningen University, The Netherlands

This project will study and document the dynamics of how local agro-ecological ("Folk Ecology", henceforth FE) knowledge is generated, shared, or withheld within community-based learning systems. Particular attention will be paid to exploring and understanding which types of learning are considered "convincing" in enriching participants' FE knowledge base as part of their dynamic expertise for agro-ecosystem management. These findings will shape the preparation of appropriate co-learning activities, experiments, and materials to support on-going farmer-researcher dialogue around improving the functioning of the local agro-ecosystems. This strategy will build on Phase One of this project (2001-04) by ensuring that FE can be strengthened through generalizable and repeatable processes rooted in local institutions, actors and processes, satisfying our ultimate goal that the co-learning activities are not inherently reliant on the project.

This project will also focus on how a community-based learning process builds farmers' confidence with unfamiliar concepts and issues, identifying which aspects of complex new knowledge systems can be "scaled up" to wider communities and by which means. We used integrated soil fertility management (ISFM) as an entry point for community activities but – because of the embedded nature of FE – innovations have had broader scope than purely addressing "soil fertility". By identifying and following innovations, we will be able to distinguish which elements are specific to the local context (social / institutional, environmental), and which have more widespread potential. These findings will useful for improving the communication strategies and decision-making abilities of extension, policy-makers, and other research activities addressing agricultural livelihoods in Western Kenya.

Phase One of this project (2001-05) established that communities of western Kenya do indeed possess and use a functioning local ecological knowledge system that we have designated a "folk" ecology to distinguish it from the "formal" or systematized "science" of ecology. This FE has evolved with the local environment to provide locally relevant concepts and understanding of the agro-ecosystem. A community-based learning process helped to make the assumptions and gaps of FE apparent through an iterative dialogue between farmers within farmer research groups (FRGs) and between farmers and researchers (see Figure 23). Making FE more accessible both to its users and to researchers is providing opportunities to improve the utility of local knowledge for making agricultural decisions and to improve the communication of new ideas between actors.

The interactive learning tools developed in Phase One combine anthropological and biophysical science methods to facilitate the exchange of knowledge and skills between farmers, scientists and other agricultural knowledge brokers. This process steadily built on the initial knowledge sets of local communities and outsiders (scientists, extension agents) to integrate the strong points of each knowledge set within a gradually evolving dynamic expertise for managing agro-ecosystems. Making FE more accessible both to its users and to researchers is providing opportunities to improve the utility of local knowledge for making agricultural decisions and to improve the communication of new ideas between actors. The goal throughout has been that FE is strengthened through processes rooted in local institutions, actors and processes, ensuring that the co-learning activities are not (either in perception or reality) overly linked to the presence of the project or of specially trained researchers.

Key outputs

1. Process: Developing more effective tools and methods of communication and dialogue

- Using "simpler" topics as entry points permits long-run empowerment and co-learning.
- Similar "lessons" have inspired very different follow-up activities in the different sites.
- Experimentation and learning on Integrated Soil Fertility Management (ISFM) topics stimulated group empowerment for other topics.

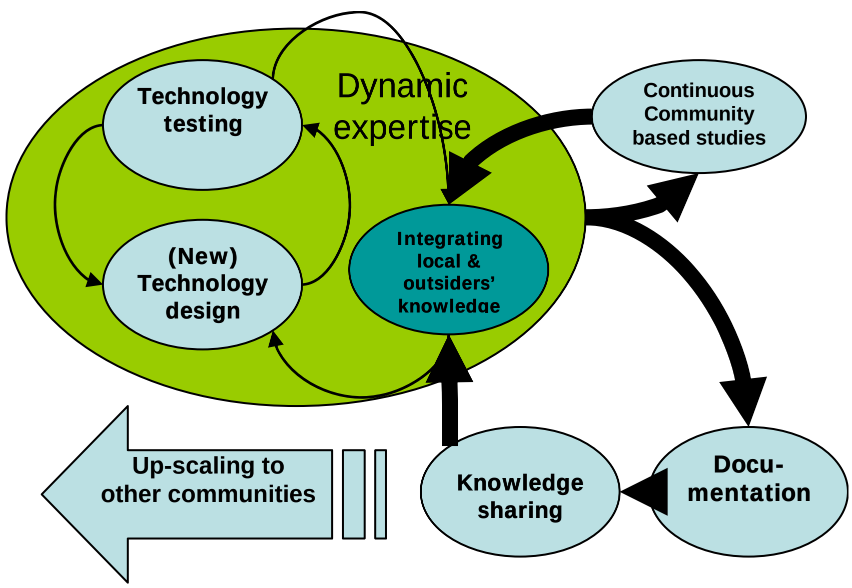

Figure 23 . The "strengthening Folk Ecology" approach. Dialogue and group activities that form part of the "Integration of local and insiders' knowledge" feed into an iterative process of collective and individual technology design and testing, which leads to the generation of local "dynamic expertise" for managing agro-ecosystems. However, understanding the processes that lead to the evolution of this "dynamic expertise" is as important as the expertise itself. Continuous community-based studies inform researchers' contributions to the integrated knowledge activities, while documentation helps both farmers and researchers share knowledge with each other, with other communities (scaling up activities), and with other knowledge brokers.

2. Process: Using innovative tools to strengthen agro-ecological and practical knowledge

- ❖ Interactive work built community understanding of previously difficult topics (i.e.: identifying nutrient deficiencies, differences between organic amendments, differences between inorganic inputs, (dis)advantages of rotating cereal and legume crops, different ways to manage local vegetables).
- ❖ Farmer-to-farmer instruction appears to downplay the experimentation process and to focus on transferring the "solutions" or "known concepts" that have emerged from the experimentations.
- ❖ The salient points of the approaches developed by Phase One, and the learning process that lead to them within our project experience have been synthesised in a preliminary Folk Ecology Manual as a set of guiding principles to be used by non-specialists.
- ❖ Farmer groups assisted the research team to generate and refine local brochures on soil ecology that integrate local and outsiders' understanding of the phenomena.
- ❖ Community-led initiatives have generated many dramas and poems relating to soil fertility management.

3. Process: Identifying and working with the diversity of institutions and networks

- ❖ Advantageous knowledge is preferentially shared within networks and actually denied to others, which contradicts the popular opinion that networks can be counted on to easily disseminate "successful" technologies.
- ❖ Collective endeavours are undermined by "individualistic behaviour" and the absence of "traditional" practices that once united communities (rituals like beer brewing or labour sharing).

4. Product: Understand and document local people's agro-ecological knowledge

- ❖ Soil ecological knowledge is not universally held or understood. The extremes of knowledge were documented, from the local "specialists" to more widespread "core" knowledge.
- ❖ Specific knowledge of soil nutrition was extremely variable but often presented in confusing or incomplete fashion.
- ❖ "Easy" techniques for learning and demonstrating soil fertility management concepts are rarely found, and unless farmer-to-farmer instruction is an ongoing process transfer of concepts is rarely possible (i.e.: only of techniques).
- ❖ The concepts of soil ecology are embedded within more holistic concerns about crop performance (climate, water, pests, markets).
- ❖ Decision-making processes and criteria relating to the allocation of scarce soil fertility management resources were also documented.

5. Product: Comparative analysis of scientific and indigenous agro-ecological knowledge

- ❖ Data sets for the community-based experimentation / demonstration activities have been analysed and interpreted with the FRG's to inform their own collective and individual experimentation
- ❖ The relevance and comparability of local indicators of soil and compost quality have been addressed in several detailed studies that have been fed back into the experimentation and demonstration processes with the FRG groups.
- ❖ Companion work within TSBF has established relationships between the soil fertility gradients identified by soil analyses within farms and the diversity that farmers identify and exploit.
- ❖ Divergences between local and scientific perspectives have also been documented on, for example, concepts of resource "quality" and nutrient deficiency.

6. Farmer empowerment

- ❖ The number of FRG has grown from five to 12 over 2001-2004. Collective, farmer-led activities grew from one to eight over the same period.
- ❖ Women have been active members and leaders of the FRG in all sites.
- ❖ Activities diversified from simple demonstrations to more experimental learning, with over 100 individual experiments designed to test and adapt the ISFM technologies.

- Participant observation of key informants and of the functioning of the FRGs demonstrated that FE is learned and modified through a variety of learning styles, and that no single approach is fully sufficient for building farmers' confidence with new or unfamiliar topics.
- The use of a community resource centre in Emuhaya (essentially a "single use" project facility) was a resounding failure and never really used except "for show". Literature and results from farmer research activities were ultimately much better disseminated by farmers themselves through local networks and groups.

7. Knowledge generation and attitude changes with other partners

Findings from the FE project, particularly about the nature and depth of soil ecological knowledge, the utility of plant indicator species in assessing soil quality, and knowledge gaps relating to soil nutrients have fed into TSBF-CIAT proposals since 2002. These include:

- A 2002 MSc thesis *Soil fertility gradients in smallholder farms of western Kenya* (by Pablo Titonell, Wageningen University),
- A broader Rockefeller Foundation supported project *Valuing within-farm soil fertility gradients to enhance agricultural production and environmental service functions in smallholder farms in East Africa* (2003-07), which has co-funding from the Belgian Inter-University Fund.

Attitude changes outside of TSBF-CIAT resulting from exposure to the FE project included:

- TSBF-CIAT's project partners in a GEF-funded project on *Conservation and Sustainable Management of Below-Ground Biodiversity*, have adapted participatory FE approaches for community dialogue into their activities in 7 country sites (Kenya, Uganda, Côte d'Ivoire, Indonesia, India, Mexico, and Brazil).
- Inclusion of discussion of FE topics and methods in soil biology / ecology course taught by Daniel Mugendi at Kenyatta University (2002+), which has prompted increased attention to local knowledge in thesis proposals in the University's Environmental Studies Programme.

Output target 2008

- ***Practical methods for rapid assessment and monitoring of soil resource base status developed***

Published work

P. Tittonell[1], B. Vanlauwe[1], P.A. Leffelaar[2], E.C. Rowe[2] and K.E. Giller[2] (2005) Exploring diversity in soil fertility management of smallholder farms in western Kenya I. Heterogeneity at region and farm scale. Agriculture, Ecosystems and Environment 110: 149-165.
[1]TSBF-CIAT Nairobi-Kenya; [2]Wageningen University, Netherlands
Abstract: The processes of nutrient depletion and soil degradation that limit productivity of smallholder African farms are spatially heterogeneous. Causes of variability in soil fertility management at different scales of analysis are both biophysical and socioeconomic. Such heterogeneity is categorized in this study, which quantifies its impact on nutrient flows and soil fertility status at region and farm scales, as a first step in identifying spatial and temporal niches for targeting of soil fertility management strategies and technologies. Transects for soil profile observation, participatory rural appraisal techniques and classical soil sampling and chemical analysis were sampled across 60 farms in three sub-locations (Emuhaia, Shinyalu, Aludeka), which together represent much of the variability found in the highlands of western Kenya. Five representative farm types were identified using socio-economic information and considering production activities, household objectives and the main constraints faced by farmers. Soil fertility management and nutrient resource flows were studied for each farm type and related to differences in soil fertility status at farm scale. Farm types 1 and 2 were the wealthiest; the former relied on off-farm income and farmed small pieces of land (0.6–1.1 ha) while the latter farmed relatively large land areas (1.6–3.8 ha) mainly with cash crops. The poorest farm type 5 also farmed small pieces of land (0.4–1.0 ha) but relied on low wages derived from working for wealthier farmers. Both farm types 1 and 5 relied on off-farm earnings and sold the least amounts of farm produce to the market, though the magnitude of their cash, labour and nutrient flows was contrasting. Farms of types 3 and 4 were intermediate in size and wealth, and represented different crop production strategies for self-consumption and the market. Average grain yields fluctuated around 1Mg ha^{-1} yr^{-1} for all farm types and sub-locations. Grain production by farms of types 4 and 5 was much below annual family requirements, estimated at 170 kg $person^{-1}$ $year^{-1}$. Household wealth and production orientation affected the pattern of resource flow at farm scale. In the land-constrained farms of type 1, mineral fertilizers were often used more intensively (ca. 50 kg ha^{-1}), though with varying application rates (14–92 kg ha^{-1}). The use of animal manure in such small farms (e.g. 2.2 Mg yr^{-1}) represented intensities of use of up to 8 Mg ha^{-1}, and a net accumulation of C and macronutrients brought into the farm by livestock. In farms of type 5, intensities of use of mineral and organic fertilizers ranged between 0– 12 kg ha^{-1} and 0–0.5 Mg ha^{-1}, respectively. A consistent trend of decreasing input use from farm types 1–5 was generally observed, but nutrient resources and land management practices (e.g. fallow) differed enormously between sub-locations. Inputs of nutrients were almost nil in Aludeka farms. Both inherent soil properties and management explained the variability found in soil fertility status. Texture explained the variation observed in soil C and related total N between sub-locations, whereas P availability varied mainly between farm types as affected by input use.

P. Tittonell[1], B. Vanlauwe[1], P.A. Leffelaar[2], K.D. Shephers[3] and K.E. Giller[2] (2005) Exploring diversity in soil fertility management of smallholder farms in western Kenya II. Within-farm variability in resource allocation, nutrient flows and soil fertility status. Agriculture, Ecosystems and Environment 110: 166-184.
[1]TSBF-CIAT Nairobi-Kenya; [2]Wageningen University, Netherlands; [3]ICRAF, Kenya
Abstract: Strong gradients of decreasing soil fertility are found with increasing distance from the homestead within smallholder African farms, due to differential resource allocation. As nutrient use

efficiency varies strongly along these gradients, such heterogeneity must be considered when designing soil management strategies, aimed at an improved overall resource use efficiency at farm scale. Here, we quantify the magnitude and study the origin of farmer-induced, within-farm soil fertility gradients as affected by biophysical and socio-economic conditions, and investigate farmers' perceptions of such heterogeneity. Farm transects, participatory resource flow mapping, farmers' classification of land qualities, and soil sampling for both chemical and spectral reflectance analyses were performed across 60 farms in three sub-locations (Emuhaia, Shinyalu, Aludeka) representing the variability found in the highlands of western Kenya. Differences between the various field types of a farm were observed for input use (e.g. 0.7–104 kg N ha^{-1}), food production (e.g. 0.6–2.9 Mg DM ha^{-1}), partial C (e.g. -570 to 1480 kg ha^{-1}) and N (e.g. -92 to 57 kg ha^{-1}) balances and general soil fertility status, despite strong differences across sub-locations. Concentration of nutrients in the home fields compared with the remote fields were verified for extractable P (e.g. 2.1– 19.8 mg kg^{-1}) and secondarily for exchangeable K (e.g. 0.14–0.54 cmol(+)kg^{-1}), on average, whereas differences for soil C and N were only important when considering each individual farm separately. Farmers managed their fields according to their perceived land quality, varying the timing and intensity of management practices along soil fertility gradients. Fields classified by them as poor were planted later (up to 33.6 days of delay), with sparser crops (ca. 30% less plants m^2) and had higher weed infestation levels than those classified as fertile, leading to important differences in maize yield (e.g. 0.9 versus 2.4 Mg ha^{-1}). The internal heterogeneity in resource allocation varied also between farms of different social classes, according to their objectives and factor constraints. Additionally, the interaction of sub-location-specific socio-economic (population, markets) and biophysical factors (soilscape variability) determined the patterns of resource allocation to different activities. Such interactions need to be considered for the characterization of farming system to facilitate targeting research and development interventions to address the problem of poor soil fertility.

K.D. Shepherd[1], B. Vanlauwe[2], C.N. Gachengo[2] and C.A. Palm[3] (2005) Decomposition and mineralization of organic residues predicted using near infrared spectroscopy. Plant and Soil 277: 315-333.

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Abstract: Characterization of decomposition characteristics is important for sound management of organic residues for both soils and livestock, but routine residue quality analysis is hindered by slow and costly laboratory methods. This study tested the accuracy and repeatability of near-infrared spectroscopy (NIR) for direct prediction of in vitro dry matter digestibility (IVDMD) and C and N mineralization for a diverse range of organic materials (mostly crop and tree residues) of varying quality (n = 32). The residue samples were aerobically incubated in a sandy soil and amounts of C and N mineralized determined after 28 days. IVDMD and quality attributes were determined using wet chemistry methods. Repeatability was higher with NIR than the original wet chemistry methods: on average NIR halved the measurement standard deviation. NIR predicted IVDMD and C and N mineralization more accurately than models based on wet chemical analysis of residue quality attributes: reduction in root mean square error of prediction with NIR, compared with using quality attributes, was IVDMD, 6%; C mineralization after 28 days, 8%; and N mineralization after 28 days, 8%. Cross-validated r^2 values for measured wet chemistry vs. NIR-predicted values were: IVDMD, 0.88; C mineralization, 0.82; and N mineralization, 0.87. Direct prediction of decomposition and mineralization from NIR is faster, more accurate and more repeatable than prediction from residue quality attributes determined using wet chemistry. Further research should be directed towards establishment of diverse NIR calibration libraries under controlled conditions and direct calibration of soil quality, crop and livestock responses in the field to NIR characteristics of residues.

K. Tscherning[1,2,3], E. Barrios[1], C. Lascano[2], M. Peters[2] and R. Schultze-Kraft[3] R. (2005) Effects of sample post harvest treatment on aerobic decomposition and anaerobic *in-vitro* digestion of tropical legumes with contrasting quality. Plant and Soil 269: 159-170.

[1]TSBF-CIAT, Cali-Colombia; [2]CIAT-Tropical Forages Project; [3]University of Hohenheim, Germany

Abstract: Legume tissue quality is a key factor for enhancement of feed resources and contribution to soil fertility in mixed crop-livestock production systems. To compare methods used by soil scientists and animal-nutritionists to assess quality of plant materials, three woody tropical legumes with contrasting qualities were used: *Indigofera zollingeriana* Miq. (Indigofera), *Cratylia argentea* Benth. (Cratylia) and *Calliandra houstoniana* (Mill.) Stan. var. calothyrsus (Meiss.) Barn. CIAT 20400 (Calliandra). Plant material of each legume was used either fresh, freeze-dried, frozen, oven-dried (60 ^oC) or air-dried in order to estimate extents and rates of aerobic degradation in litterbags on the soil during 140 days and anaerobic degradation in an *in- vitro* gas production experiment during 144 h. Results showed, that aerobic decomposition rates of leaf tissues were highest for Indigofera (k=0.013 day^{-1}), followed by Cratylia (k=0.004 day^{-1}) and Calliandra (k=0.002 day^{-1}). Gas production rates evaluated under anaerobic conditions, were highest for Indigofera (k=0.086 h^{-1}), intermediate for Cratylia (k=0.062 h^{-1}) and lowest for Calliandra (k= 0.025 h^{-1}). Decomposition and gas production rates differed ($p<0.001$) among species. Differences between post harvest treatments were not statistically significant ($p>0.05$). The extent of decomposition was highest for Indigofera (82.5%, w/w), followed by Cratylia (44.6%) and Calliandra (26.4%). The extent of gas production was highest for Indigofera (218.8 ml), followed by Cratylia (170.1 ml) and Calliandra (80.1 ml). Extent of decomposition and extent of gas production were significantly different ($p<0.001$) among species. In contrast to the extent of decomposition, the extent of gas production was affected ($p<0.001$) by sample post harvest treatments. Highest gas production was observed for the fresh and frozen treatments. The forage quality parameters that best correlated with aerobic and anaerobic degradation were lignin+bound condensed tannins, lignin+total condensed tannins/N, indigestible acid detergent fibre (IADF) and *in-vitro* dry matter digestibility (IVDMD). Results showed that differences in decomposition and digestibility were more related to intrinsic plant quality parameters than to changes in tissue quality induced by post harvest treatments. In addition, we found that rate of aerobic degradation of legume leaves on the soil was highly correlated ($r>0.80$, $p<0.001$) to IVDMD and gas production ($r=0.53$, $p<0.001$). These results indicate that plant measurements (IADF, IVDMD and gas production) used to assess forage quality in animal nutrition studies are more rapid and resource saving predictors for aerobic decomposition of tropical legumes than initial plant quality ratios (lignin+polyphenols/N and lignin+total condensed tannins/N) commonly used by many researchers. Furthermore, this study confirms the potential usefulness of IVDMD for screening tropical legumes for soil fertility management.

B. Vanlauwe[1], C. Gachengo[1], K. Shepherd[2], E. Barrios[3], G. Cadisch[4] and C. Palm[5] (2005)
Validation of a resource quality-based conceptual framework for organic matter management. Soil Science Society of America Journal 69: 1135-1145.
[1]TSBF-CIAT (Kenya); [2]ICRAF; [3]TSBF-CIAT (Colombia); [4]University of Hohenheim; [5]Columbia University, USA
Abstract: Organic resources (OR) are essential inputs in tropical farming systems and their decomposition dynamics are related to their quality. A Decision Support System for organic N management (DSS) has been earlier proposed that subdivides OR in 4 classes depending on their N, lignin, and soluble polyphenol contents. To validate this DSS, a 28-day aerobic incubation experiment was initiated with 32 OR, mostly crop and tree residues. The OR contained 0.14 to 5.32% N, 2.5 to 29.5 % lignin, and 0.4 to 14.8% soluble polyphenols. In-vitro dry matter digestibility (IVDMD) ranged from 7 to 82%. After 28 days, CO_2-C production varied between 199 and 905 mg CO_2-C kg^{-1} soil, and mineral N contents between 5 and 109 mg N kg^{-1} soil. Based on N mineralization data, 3 classes of OR were evident: class A with N release > 0, class B with N release = 0, and class C with N release < 0. Criteria to separate those classes were based on the OR N and polyphenol content and cut-off values between the classes agreed well those proposed in the original DSS. For class A OR, N mineralization was related with lignin/N ratio (except for *Gliricidia* residues) and for class C OR with N content. Short-term mineralization data supported the existence of 3 classes of OR instead of 4 originally proposed by the DSS. However, due to the multiple functions OR fulfill, some acting in the medium to long term, it is likely that the original 4-class concept will prevail.

E. Velásquez [1,2], P. Lavelle[1], E. Barrios[2], R. Joffre[3] and F. Reversat[1]. (2005) Evaluating soil quality in tropical agroecosystems of Colombia using NIRS. Soil Biology and Biochemistry 37: 889-898.

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Abstract: Near infrared reflectance spectroscopy (NIRS) analysis was used to discriminate soils of different agroecosystems in Colombia, with different contents and qualities of organic matter chemical and biological properties. Correlations were sought between absorbance's in wavelengths classes as determined by NIRS and a set of variables describing soil quality grouped into three classes: (i) chemical variables (Ca, Mg, K, exchangeable Al, total P, P-Bray II), (ii) organic variables (total C, total N, N-NH^+_4, N-NO^-_3, respirometry and carbon content in different fractions separated by the LUDOX physical methods) and (iii) NIRS variables quantifying the absorptions in the near infrared region separated into 101 classes of wavelength). For each group of variables, a PCA, associated with discriminant analysis, was run. Each class of variables separated the different soil-use systems (***P <0.001) similarly. Co-inertia analyses among the different groups of variables verified the sensitivity of the NIRS in detecting significant changes in the soil chemical and organic composition, as well as in microbial activity. These results show the high potential of the NIRS for evaluating soil quality in large areas, rapidly, reliably and economically, thereby facilitating decision-making with respect to soil management and conservation.

Completed work

This ped is my ped: visual separation and NIRS spectra allow determination of the origins of soil macro-aggregates

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Macroaggregation is a highly dynamic attribute of soils that is claimed to have a significant impact on their ability to store C and conserve nutrients. There is growing awareness that the dynamics of aggregate production and destruction over time is important to their function as microsites for C sequestration. The effect of different land use practices on their dynamics at different scales and the combined effects of physical, chemical and biological processes involved, are also of great importance. A major obstacle to understanding macroaggregate dynamics is our inability to identify the origins of the different types of aggregates found in soils, their turnover times and positions within the soil matrix.

We propose here a general methodological approach in which the origin of aggregates separated according to visual criteria could be determined by comparing their specific organic matter signatures assessed by NIRS to signatures of biogenic structures produced by soil ecosystem engineers (invertebrates and roots) living in the same soil. A visual method of aggregate separation derived from the highly detailed Topoliantz et al. (2000) assessment technique is proposed and validated across 61 sampling points regularly distributed across a watershed in Nicaragua and representing crops, pastures, forests, coffee plantations and fallows. Coinertia analyses among soil macroinvertebrate communities and the matrix of soil morphological variables showed highly significant relationships. In Amazonian forest patches and pastures from the state of Pará in Brazil, 75 different types of biogenic structures were collected at the soil surface and on tree trunks (Figure 24) and analysed by the NIRS spectral method. We then verified that biogenic structures produced by a wide diversity of soil invertebrates in ecosystems derived from the rainforest in Eastern Brazil have significantly different NIRS (Near Infra Red Spectrometry) spectral signatures.

Figure 24. Example of different types of soil biogenic structures.

Significant differences were observed among the different types of structures that could be grouped according to their broad phylogenetic origin, with large inter-specific differences. NIRS analyses performed on soil macroaggregates separated by our visual technique and large casts deposited at the soil surface by the earthworm *Andiodrilus pachoensis* suggested that this earthworm is not responsible for production of the bio-organic aggregates that comprise a large proportion on the soil volume in this soil.

The effect of mixing prunings of two tropical shrub legumes (*Calliandra houstoniana and Indigofera zollingeriana*) with contrasting quality on N release in the soil and apparent N degradation in the rumen

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Lack of synchronization between N released from prunings applied to the soil as green manures and crop uptake as well as optimization of protein digestibility for ruminants, remain major research objectives for the selection of multipurpose tree and shrub legumes (MPT) for mixed smallholder systems in the tropics. Prunings of the high tannin, low quality MPT *Calliandra houstoniana* CIAT 20400 (Calliandra) and the tannin free, high quality MPT *Indigofera zollingeriana* (Indigofera) were mixed in the proportions 100:0, 75:25, 50:50, 25:75, and 0:100 (w/w) in order to measure the aerobic rate and extent of N release in a leaching tube experiment, and the anaerobic extent of N degradation in an *in-vitro* gas production experiment.

Parameters measured in Calliandra:Indigofera mixtures were compared to theoretical values derived from single species plant material (i.e. 100:0 and 0:100). Aerobic N release and apparent anaerobic N degradation increased with increasing proportion of the high quality legume (Indigofera) in the mixture (Figure 25). While N release in the soil was lower than theoretical values in the mixture 50% Calliandra/50% Indigofera, this was not the case with apparent anaerobic N degradation with the same mixture. Aerobic N immobilization was more pronounced for the mixture 75% Calliandra/25% Indigofera than for 100% Calliandra and negative interaction was observed with apparent anaerobic N degradation in the mixture 75% Calliandra/25% Indigofera. Plant quality parameters that best correlated with aerobic N release and apparent anaerobic N degradation in the rumen were lignin + bound condensed tannins (r = -0.95 and -0.95 respectively, p<0.001). In addition, a positive correlation (r = 0.89, p<0.001) was found between aerobic N release in the leaching tube experiment and apparent N degradation in the *in-vitro* anaerobic gas production experiment.

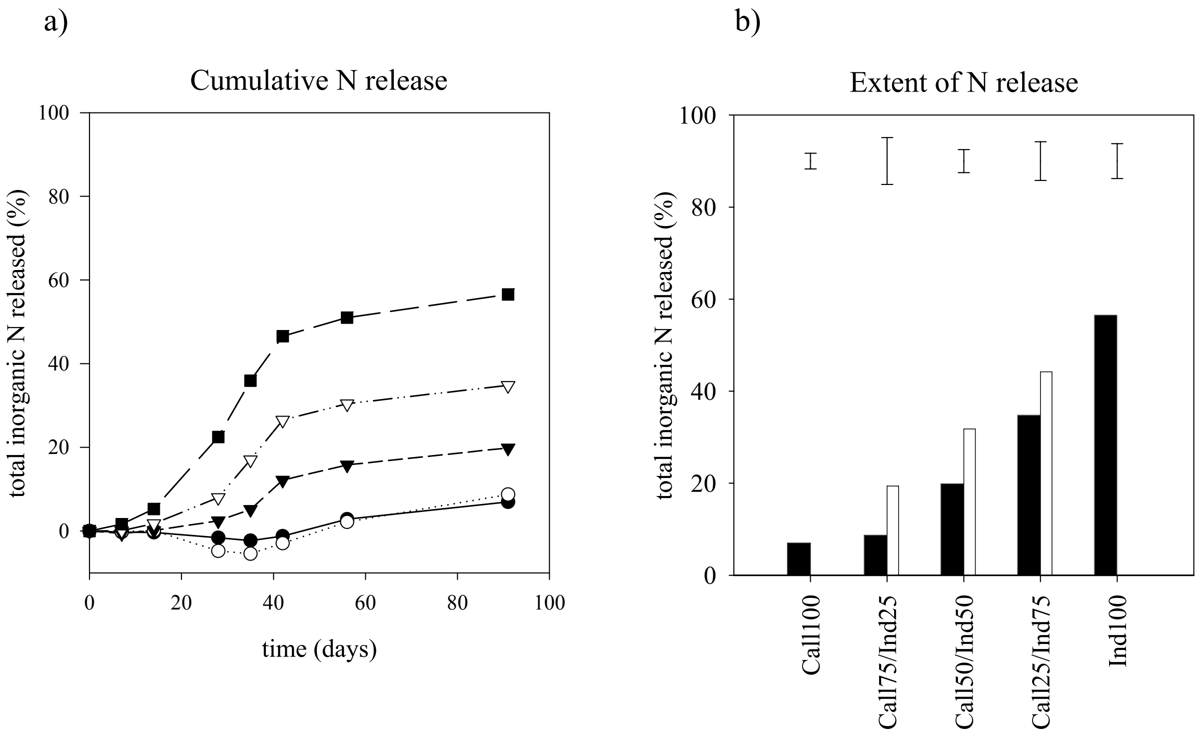

Figure 25. a) Cumulative N release during 91 days of aerobic incubation of Calliandra (Call) and Indigofera (Ind) mixed in the proportions: 100:0, 75:25, 50:50, 25:75, 0:100 w/w and b) extent of N release after 91 days of aerobic incubation of Calliandra (Call) and Indigofera (Ind) mixed in the proportions: 100:0, 75:25, 50:50,25:75,0:100w/w, black bars = measured value, white bars = theoretical value, error bars = standard error of the difference in means. Values are in % of total inorganic N released.

Our results indicate that mixtures of low (low N, high condensed tannins, high fiber concentration) and high (high N, no condensed tannins, low fiber concentration) quality legumes can be utilized to manipulate aerobic N release in the soil and apparent anaerobic N degradation in the rumen of animals. Manipulation of aerobic N release and apparent anaerobic N degradation through mixing of high and low quality MPT can be a useful method to minimize N losses in the rumen and in the soil. The high correlation (r= 0.89, p<0.001) observed between apparent anaerobic N degradation and aerobic N release has cost-saving implications for screening legumes for their green manure potential given the shorter duration required with the anaerobic system.

Work in progress

Adoption potential of improved varieties of soybean in the farming systems of Kenya: ex-ante analysis

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In Kenya, it is common knowledge among the stakeholders in the agricultural sector that soybean [(*Glycine max* L.) Merr.] is not that new in the farming systems, having been introduced as far back as 1904. It is also well known that many development agencies have in the past promoted soybean production in the country. Soybean production in Kenya has, however, remained extremely low and insignificant and does not show up in FAO statistics. Many farmers do not grow the crop and those who grow it plant mostly local varieties (such as *Nyala*, *B. Congo*, *Bossier*, *Duiker*, *Hill*, and *Voster*) that are low yielding with little or no biological nitrogen fixation. Some of the local soybean varieties also need to be inoculated with *Rhizobium* for enhanced yield and many farmers are either not aware of this need or cannot afford the procedure. As a result only few farmers presently grow soybean in the farming systems of Kenya. These few farmers devote only a small fraction of their land and other resources to soybean production. Farmers prefer to give more attention to other legumes especially the common bean (*Phaseolus spp*.) that they are familiar with. Due to the limited attention paid to soybean production by the farmers, the annual production of soybean in Kenya has been estimated at about 5 000 metric tons per annum.

The above abysmal performance of soybean notwithstanding, due to the demonstrated importance of soybean in improving the livelihoods of smallholder farm households and in improving the natural resource-base of many farming systems elsewhere in Africa (e.g., Nigeria, Zimbabwe, and South Africa), some research and development agencies have commenced a new effort at promoting soybean in the farming systems of some East African countries including Kenya. For instance, over the last three years, the Tropical Soil Biology and Fertility institute of the International Center for Tropical Agriculture (TSBF-CIAT) has been conducting on-farm trials (both farmer-managed and researcher-managed) aimed at determining the adaptability and performance of improved promiscuous soybean varieties developed in Nigeria by the International Institute of Tropical Agriculture (IITA) under various farming systems and conditions in Kenya.

Preliminary screening results indicate that over ten of these improved soybean varieties from Nigeria exhibit excellent performance under the agricultural production conditions in western Kenya. Among the other attributes of the improved soybean varieties are their potential to improve soil fertility through more atmospheric nitrogen fixation than *Nyala*, the most popular local variety.

Based on the promising nature of the recent efforts at researching for and promoting improved soybean varieties that are high yielding and soil fertility-improving through their ability to fix atmospheric nitrogen (among other numerous attributes) in the farming systems of Kenya, TSBF-CIAT received financial support from the Rockefeller Foundation to enhance its current effort aimed at promoting soybean in the farming systems of East Africa (Kenya, Uganda, and Tanzania). Following this financial gesture, TSBF-CIAT has been expanding its soybean research especially in the areas of varietal screening and agronomy in order to select and recommend to farmers the best bet of the varieties that are high yielding, high nitrogen-fixing, and adaptable under different conditions in the farming systems of Kenya, Uganda, and Tanzania. TSBF-CIAT is also empowering the farming communities on various methods of processing soybean for home utilization and household cash income – an important step to ensure sustainability.

Since many past projects aimed at promoting soybean in East Africa (including Kenya) region could not result in the take off of soybean, TSBF-CIAT considered it crucial to carry out ex-ante analysis of the adoption potential of the new promiscuous soybean varieties in the farming systems of Kenya, essential before committing scarce resources in promoting adoption and other scaling out and scaling up activities.

The overall objective of this paper is to carry out an ex-ante analysis of the adoption potential of the new improved soybean varieties in the farming systems of Kenya. The specific objectives are: (1) to assess the biophysical, environmental, and agro-climatic conditions of the various farming systems in Kenya in relation to the performance of soybean, (2) to evaluate the attributes of the improved soybean varieties and highlight their important characteristics that will likely influence adoption in the farming systems of Kenya either positively or negatively, (3) to examine the policy environment in relation to the probability of adoption of improved soybean varieties in the farming systems of Kenya, (4) to evaluate the existing institutions in relation to their support or non-support of farmer adoption of the improved soybean varieties, (5) to assess the socio-economic characteristics of the farm households in relation to the probability of adoption of improved soybean varieties, and (6) to determine the potential economic benefits of the adoption of improved soybean varieties in the farming systems of Kenya. All these would help to ensure proper targeting of improved soybean varieties and hence eventual widespread uptake.

Overall, the conditions of the farming systems of Kenya are suitable and can support the adoption of the improved soybean varieties. Eight important broad factors were assessed to reach this conclusion. These are: (i) Biophysical, environmental, and agro-climatic conditions, (ii) Conducive farming practices, (iii) Attributes of the improved soybean varieties, (iv) Political stability and policy environment. Others are (v) Institutions, (vi) Socioeconomic characteristics of farm households, (vii) Economic benefits, and (viii) Farmer participatory approach in improved soybean development and promotion. Across these factors, the potential contributions of improved promiscuous soybean varieties in significantly improving farm productivity have been amply demonstrated. This will most likely attract the interest of the farmers. There is, therefore, sufficient evidence that farmers will likely adopt the improved soybean varieties in Kenya. This ex-ante result indicates that the improved soybean varieties (especially those selected by farmers in different locations) merit further attention and investment.

Determination of the potential of selected legume species and varieties to trigger suicidal germination of *Striga hermontica*

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Striga hermonthica (Del) Benth; a root parasite weed is a major constraint in cereal production in sub-saharan Africa. A single S. *harmonthica* plant can produce as many as 50,000 seeds and remain viable for more than 14 years. Prodigious seed production together with prolonged longevity and special germination requirements makes striga a difficult weed to control. Conditioned striga seeds will only germinate when exposed to synthetic germination stimulant or natural stimulants present normally in the root exudates of many hosts or non-host species. Once germinated, the striga seedling must attach to a host root within 3-5 days or the seedling dies. Hence a sustainable control option for the African resource poor farmers to reduce S. *hermonthica* parasitism is the use of trap crops, particularly legumes that stimulate germination of the parasite seeds but are non-hosts in rotation or intercropping with cereals. However the ability of leguminous trap crops to stimulate S. *hermonthica* seed germination, both between and within species, is variable. The objective of this study was to identify and select in vitro soybean accessions with high ability to stimulate germination of *Striga harmonthic*a seeds.

Roots from thirty-two soybean accessions were tested in laboratory for their ability to stimulate striga hermonthica seed germination. For reasons of comparison, roots of Desmodium, Mucuna, and three maize varieties were included. Strigol and distilled water were used as baseline and control, respectively. Test plants were grown for 21 days after which the roots were harvested and excised into 1cm long pieces. Excised roots (1g) were put in an aluminum foil ring at the center of a petridish lined within a double layer regular filer paper moisten with 5ml distilled water. Glass fibre filter paper disks with conditioned striga seeds were then arranged in four lines to form a cross radiating from the central aluminum ring. Distilled water or strigol was then pipetted over the root pieces in the aluminum foil ring. Petri dishes were then sealed with parafilm, wrapped in aluminum foil and incubated at 30^{o}C for 48hrs. After the incubation period the petri dishes were opened and the number of striga seeds germinated on each glass fibre dish out of the total number of seed son that dish counted using dissecting microscope.

Seeds treated with strigol displayed high germination, which was not significantly different from stimulation due to soybean accessions like TGX1448-2E and TGX1740-2F (Table 15). Seeds treated with distilled water did not show any significant germination (germination % of 0.1%). Soybean accessions were significantly different in their ability to stimulate S.*hermonthica* seed germination with some soybean accessions showing a higher germination potential than Desmodium and Mucuna. Maize variety WH502 was slightly more sensitive, causing higher germination of S.hermonthica seeds compaired to the other maize varieties.

Conclusions: In-vitro techniques show a high variability within the soybean genepool for triggering suicidal Striga germination. This needs to be confirmed in pot and field trials with a selected number of best-bet accessions before specific varieties can be advocated as optimal entry-points in striga-affected areas.

Table 15. *Striga hermonthica* germination percentage caused by roots from 21 days old seedlings in descending order

Species	Variety	%Striga germination
Baseline stimulants	Strigol (GR24)	41.3
Soybean	TGX 1448-2E	38.8
Soybean	TGX1740-2F	38.7
Soybean	TGM76	38.3
Soybean	TGX1876-4E	37.9
Soybean	TGM09	37.9
Soybean	TGX1831-32E	37.0
Maize	WH502	35.9
Soybean	TGX1871-12E	34.2
Soybean	TGM4	33.8
Mucuna	Mucuna	33.4
Maize	Nyamula	33.3
Maize	KSTP94	32.4
Soybean	TGM19	31.5
Soybean	TGX1895-33F	28.7
Soybean	TGX1893-10F	27.9
Soybean	TGX1894-3F	27.1
Soybean	TGX1895-49F	26.7
Desmodium	Desmodium	35.3
Soybean	Namsoy 4m	35.0
Soybean	TGM11	26.4

Species	Variety	%Striga germination
Soybean	J-499	25.9
Soybean	Nyala	25.6
Soybean	Marksoy 1a	25.1
Soybean	TGM93	22.0
Soybean	TGM96	21.4
Soybean	TGM20	20.6
Soybean	TGX1830-20E	19.3
Soybean	TGM60	16.5
Soybean	TGX1898-12F	15.8
Soybean	TGX1895-4F	15.2
Soybean	TGX1893-7F	14.6
Soybean	TGX1844-18E	13.9
Soybean	TGX1895-6F	12.7
Soybean	TGX1869-31E	8.3
Soybean	TGX1878-7E	4.7

Output target 2008

- ***The social, gender, and livelihood constraints and priorities affecting the sustainable use of soils have been identified, characterized, and documented through case studies using innovative methods***

Work in progress

Do farmers "do" soil fertility?

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This paper analyses farming practices among smallholder farmers of Butula, Chakol, Emuhaya and Matayos in western Kenya. It assesses the soil fertility worth of these practices that included use of different organic manures (compost, FYM, mulches) of varying qualities and traditional systems (such as crop rotation, natural fallows, intercropping) that depended on complex local logic. This local logic was not by and large geared toward soil fertility, rather the underlying factors included: available materials; tradition and traditional knowledge; food; economic needs and abilities; land size, labour, new knowledge, and the different interpretations of it, which shaped new dynamism. New dynamism resulted in strengthened ecological knowledge of few local farmers, which nevertheless, did not qualitatively percolate out to other individuals within and outside the sites. This paper points out that accelerating dynamism (i.e. strengthening the positive vitality) of local logic is the best approach to enhance soil fertility management among smallholder farmers of western Kenya.

Whose land degradation counts? Redefining the concept and role of "local knowledge" in soil fertility management

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Land degradation is presented as a major risk for Africa's soils by influential agricultural and environmental studies. Yet technology-driven interventions have failed to stimulate agricultural productivity or to reverse apparent continent-wide problems of soil fertility decline. Soil scientists are therefore increasingly working with multidisciplinary teams and considering the role of local agro-ecological knowledge in natural resource management. This paper uses examples from a community-based learning project in western Kenya to examine how local soil fertility management practices are informed by knowledge generated and refined experientially. This "local" knowledge defines land degradation within a social context and constructs models of soil and soil fertility useful for local livelihood objectives. While the local knowledge of soils is not at risk of commodification as such, scientific efforts to "validate" local soil knowledge in technical terms often backfire by trivialising it, given the embedded and situational nature of soil fertility management knowledge. The paper traces how local understandings of soil types, the nature of soil fertility and land degradation, and of the benefits of organic and inorganic inputs compare with the perspectives of scientists. The western Kenyan example demonstrates that soil fertility managers and researchers must acknowledge the multiplicity and diversity of knowledges operating, evolving, and adapting locally.

Strengthening competitiveness through research: How rural innovations support market-led organic agriculture in Uganda

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As a response to the worldwide demand, certified organic production is increasing rapidly in Uganda. By mid 2005, about 40.000 certified organic farmers produced cotton, sesame, coffee, cocoa, fruits and other commodities for export. Uganda has the fourth largest number of certified organic farmers in the word and is among the top organic exporters in sub-Saharan Africa. In organic farming, smallholders gain from higher product prices and a more sustainable natural resource management, two mechanisms that are aimed at contributing to the United National Millennium Development Goals. Whilst recent developments of the sector have been impressive, there are numerous agronomic, economic and social factors that act as barriers to the further development of organic agriculture in Uganda. The future expansion of organic exports not only depends on the growing export markets overseas, but on pro-organic research that backs organic growers and traders to produce more of what is demanded from the marketplace.

Building farmers' capacities to learn about biological and ecological complexity using participatory approaches and involving farmers in experimentation is a critical success strategy for empowering farmers to be able to learn and to innovate. The purpose of this ongoing research project (2004–2007) is to increase farmers' competitiveness on organic markets by developing and testing ways to forge multi-stakeholder 'learning alliances' at the local and national level. The project is implemented in two pilot sites in western and central Uganda. In each site action research supports farmers in establishing linkages with organic markets. This transition process from traditional to market-led organic production is based on the 'Enabling Rural Innovation' (ERI) approach developed by CIAT.

At each site, the steps in the implementation of this approach for building assets of small-scale organic producers are: (i) participatory diagnosis with the community, with strong emphasis on gender and stakeholder disaggregation, (ii) participatory market analysis to identify market opportunities for competitive and profitable products that farmers are able to produce, (iii) prioritization of opportunities and selection of household food consumption and agroenterprise options disaggregated by gender, (iv) formation of a farmer research group and a market research group to represent the community, and building their capacity to participate in evaluating market orientated and technology options, (v) planning and implementation of experimentation and marketing strategies with farmer research and market research groups, (vi) development of community enterprises and strengthening community Agroenterprise initiatives, (vii) participatory monitoring and evaluation, and learning to derive lessons and impacts, and scaling-up and out of research results and of community enterprise development process, and (viii) feedback of results to the community and identification of further research questions.

Given the potential poverty reducing effects the scientific community needs to re-prioritise research themes and to adhere to a new set of conceptual principles that guide pro-organic research. So far the ERI approach has proven to be useful in facilitating a market-led, farmer-owned, transition process from traditional to organic agriculture as it forges 'learning alliances' between farmers and their research and development partners. Examples will be presented on how this approach has enabled farmers to access new market information (e.g. prices, quantities, quality) and new research products (e.g. disease resistant germplasm, variety evaluation for export, investing in natural resources and soil fertility) on critical aspects of production and how they have used this new information to develop competitive and profitable export organic agroenterprises.

Identifying and overcoming the limitations for implementing conservation farming technology in the Fuquene watershed (Colombia) by integrating socioeconomic and biophysical research with financial mechanisms

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The Fuquene Lake has been progressively invaded by aquatic vegetation. Nowadays, about 80% of the original lake surface is entirely covered by these plants and some of these parts are fully filled with sediments. Due to the high degree of degradation, the restoration and conservation of this lake has become one of the main objectives for the Colombian environmental authorities since it can affect 27 aqueducts that are supplied by the lake. Regarding this environmental concerns, CAR accepted CONDESAN-GTZ support to conduct research and development actions in order to:

- Identify the point and non point sources of pollutants,
- Prioritize areas according with their responsibility in the lake eutrophication,
- Apply experimental economics methodologies to explore willingness of water users and farmers to cooperate for modifying negative environmental externalities,
- Understand how is the poverty profiles and how are spatially distributed,
- Conduct ex-ante analysis to determine the impact of changing conventional tillage practices by farming conservation practices, and
- Design actions to modify the environmental externalities affecting it.

The environmental and socioeconomic evaluation showed that implementing farming conservation practices in the prioritized areas could reduce the negative environmental externalities by about 50% as the net income and employment opportunities are increased.

In spite of GTZ (EPC)-CAR have been working jointly in the extension of conservation farming practices and adjusting the required equipment to implement direct drilling and reduced tillage, the adoption of this technology was still incipient. The economic games applied in the field demonstrated an important potential of collective action to achieve technological changes. Specifically, about 80% of potato and cereal farmers invited to the games were willing to implement conservation farming practices. On the other hand, water users are willing to pay to upstream farmers as an incentive for promoting sustainable land management if there is a direct negotiation and not the interference of the environmental authority. Thus, collective action for providing better environmental services highly depends on the possibility of negotiating among those actors and on their awareness of the relationship between land use and hydrological externalities.

Although, production costs and productivity surveys showed that by incorporating farming conservation practices the net income is increased, the technological change is not reached readily since it is required an initial investment higher than with conventional tillage since it is necessary the introduction of green manures prior to the conventional crop is sown. Then, to increase the adoption of the technology, the project has been promoting a financial mechanism. The mechanism was created to investigate if the suspected restricted financial capacity of small farmers was constraining a massive technological change in the watershed. To reach this objective CONDESAN-GTZ (AWP) make an agreement with GTZ(EPC)-CAR to assure the technical assistance needed for the implementation of the practices. Also, two farmers associations were introduced to the partnership acting as direct beneficiaries of the financial mechanism and also as intermediaries between CONDESAN and the smallest farmers who do not belong to the associations.

The financial mechanism consists in providing credits to the two farmers associations that were committed to distribute the funds to their associated farmers that are willing to incorporate conservation farming practices. The mechanism was initiated in 2004 and since then, it has made significant progress in two phases. In the first phase a fund was created by CONDESAN-GTZ and managed directly by the farmers associations. The fund resources were used as capital for credits with a low interest rate. As a result, in 100 hectares minimum tillage and green manures were incorporated. However, it did not necessarily reach the target population that is the poorest farmers of the watershed and the available project funds were not enough to respond to the current demand. For this reason a second phase was designed.

In the second phase (2005), a strategic alliance was built with FINAGRO (The National Fund for Financing Farming) in order to facilitate the incorporation of small farmers to the financial sector. In particular, the project funds have been used as guarantee of the 20% of the farmers contracted debt. The resources are deposited in FINAGRO, who guarantees the rest of the debt and provide the credits. In this strategic alliance, CIAT is committed to certify that any Fuquene farmer benefited with the FINAGRO credits for conservation agriculture, are implementing the technology properly. Also, CIAT should demonstrate the impact of conservation practices on the watershed environmental services.

With the new scheme developed in the second phase, CONDESAN- GTZ aims to multiply the existing resources for investment and also, to provide incentive for the use of existing governmental guarantee facilities that are not widely used by the small farmers. This is because of: 1) the lack of commercial banks willingness to lend money to producers that can not offer their own guarantees and 2) the lack of motivation of the farmers to apply for FINAGRO guarantees due to the transaction costs and the time needed for the preparation of requirements and the respective approval. With the guarantee fund provided by CONDESAN-GTZ, the process for accessing to this guarantees and credits is accelerated as the farmers are supported now with resources deposited directly in FINAGRO. This is the first case in Colombia where conservation farming is accepted for receiving guarantees and credits from the financial system. To make this possible FINAGRO is adjusting its credit schedules because from now on it has to include the additional time needed to sow green manures before a commercial crop is established.

These development actions are not only promoting technological changes but are creating in situ research scenarios for investigating the real constraints for using the soils in a sustainable manner. Therefore, CONDESAN-GTZ expects to determine the biophysical ex-post impact of these practices on the soils and lake conditions and the social and economic benefits caused by the technological change. If the results are positive, these practices will be incorporated as an alternative that can be compensated by a payment for environmental service scheme also promoted by the project.

The use of stable isotopes for identifying the sources of Nitrates and Phosphates in Fuquene Lake
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One of the key elements in devising payments or compensation schemes for environmental services is the thorough knowledge about the environmental service itself and the changes or modifications this is facing. This is the case for the water quality of Fuquene Lake in Cundinamarca, Colombia. The lake is suffering with eutrophication due to the incoming loads of nutrients from urban and agricultural activities. Nutrients such as nitrogen (N) and phosphorous (P) are carried in sediments, urban wastes and leached fertilizers. To tackle this problem, researchers were asked about methods to clarify the origin and quantities of pollutants. The use of stable isotopes was sought as one of the strategies in parallel with standard monitoring and modelling techniques. We present a short summary of progress in the use of stable isotope methodology.

In order to have a better understanding of the historical and current status of water resources in the zone, data from previous studies were collected. Data were collected from the National Geological Institute (INGEOMINAS, Instituto Nacional de Investigaciones Geologico-Mineras), Regional Autonomous Corporation (CAR, Corporacion Autonoma Regional), National Geographic Institute (IGAC, Instituto

Geografico Agustin Codazzi) and the National Institute of hydrology and environmental studies (IDEAM, Instituto de Hidrología, Meteorología y Estudios Ambientales). The collected data consisted of water quality measurements on specific locations at different points in time. These different sources were analyzed and when required integrated using different modeling techniques. L-Thia, SWAT and logistic regression models were used to estimate the location of sources. The produced outputs were used to guide water-sampling campaigns in 2004 and 2005 either for stable isotopic and standard measurements. Portable monitoring devices were used in the field and validated with standard laboratory techniques using an atomic absorption spectrophotometer. Isotope results were used to identify the location and type of source and standard measurements to estimate the volumes of different locations. With the delimitation of contributing areas it was also possible to identify the predominant land uses in each contributing zone.

Different techniques and methods have been used by different organizations at different times. This situation generates lack of consistency and reduces the possibility of using the data in an integrated way. There is no simulation method that can use this data as a validation set. Probabilistic methods could be used but their results are restricted to the sampled sites, which in this case do not cover the whole study area.

In spite of the differences among studies, the studies report similar places contributing the most. Such is the case of Tausa and Cucunuba surroundings, which are located at the south of the study region where part of the charcoal mines is also located. Potato farms are also very common in the upper part of Tausa (Figure 26).

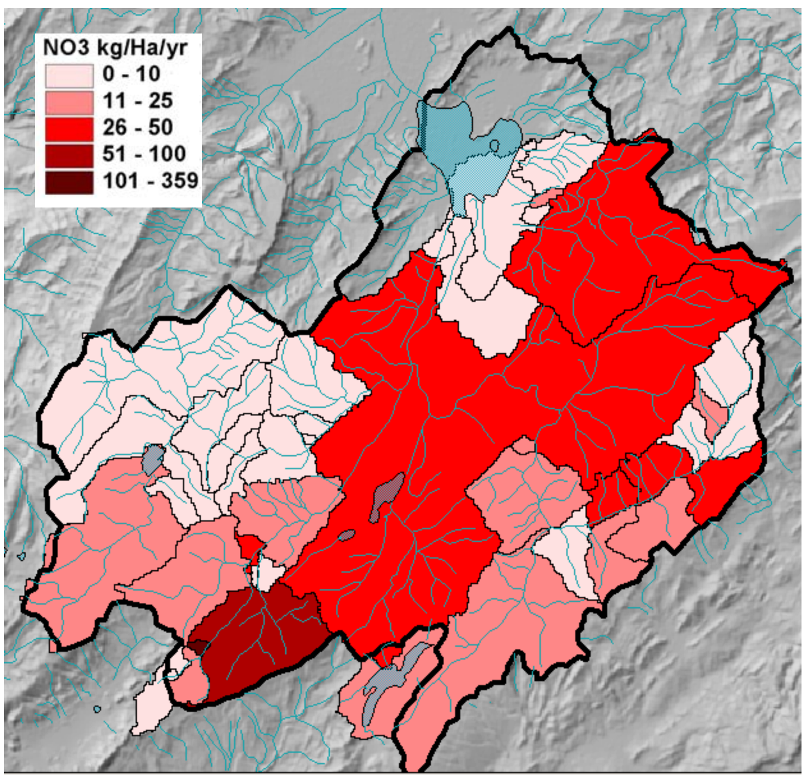

Figure 26. Ten years average total nitrate contribution in kg ha^{-1} considering the nitrate concentrations found in 2005 sampling made by CIAT.

Based on the use of stable isotopes (Figure 27), the discrimination of sources allows us to assign to the sediments the higher contribution source of nitrates with a value of 43.6% followed by fertilizers with 38.3% and organic wastes with 18.1%. Summing up the three sources, pasture area is contributing with 17.4% while cropland is accounting for the 43%. Nitrates attached to sediments are accounting for more than a half of cropland contribution.

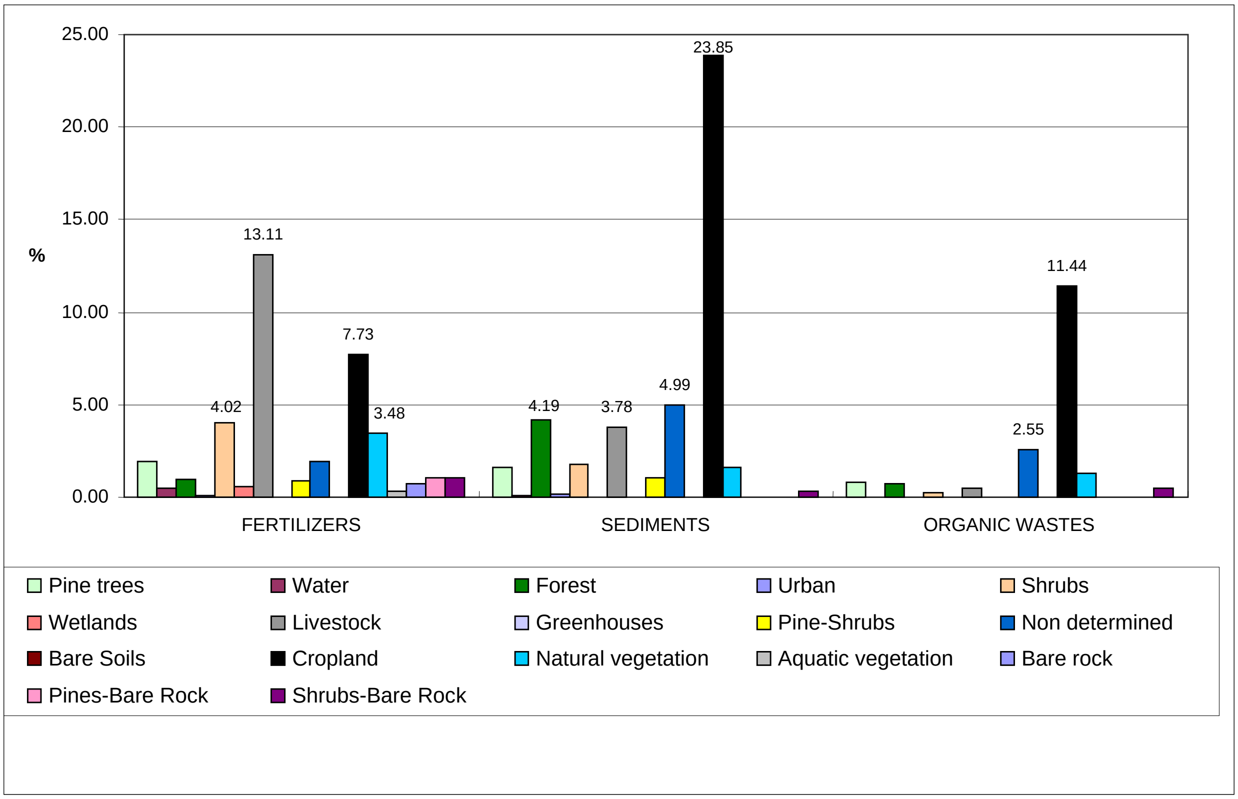

Figure 27. Percentage of existing land uses on areas that are considered specifically as predominant sources of pollutant based on the use of stable isotopes.

Progress towards achieving output level outcome

- *Principles, concepts and methods inform technology and system development*

The objective of Output 1 is to develop methods and principles that underlie efforts to improve the health and fertility of soils. Such international public goods (IPGs) foster innovative soil management strategies and inform the technology development and adaptation processes conducted in Output 2. This output has two aspects: one is the improved understanding of the process informing the development of technologies and systems that improve the fertility of soils and soil health; and the second aspect concerns the contribution of the improved soil health and fertility to resilient production systems and sustainable agriculture.

Development of principles, concepts and methods involve continuous and detailed review of the literature to identify key research questions and research gaps, that are translated into laboratory, greenhouse and field experiments with increasing on-farm research activities. Robust techniques for analyzing heterogeneity of socio-economic and biophysical factors influencing soil fertility management and soil fertility outcomes have now been developed, tested, and applied in a diversity of environments and socio-cultural settings. Research has focused more and more on land management practices, like agroforestry, reduced-till and crop-livestock systems, and their possible impacts of soil fertility and the natural resource base. Impacts evaluated range from changes in populations of soil microorganisms, changes in soil organic matter, soil P pools and water infiltration, changes in nutrient use efficiency in response to organic and inorganic nutrient sources, to changes in nutrient and resource flows at the farm and village scales in Africa and Latin America. Greater insights have been gained by the careful consideration of the agro-ecological and socio-economic contexts where these land management practices are tested thus increasing our capacity to develop relevant technologies and methods for sustainable land management. The studies into resource allocation on farm and soil fertility gradients within and across farms, are an example. Several studies on fallow management (looking at options for ISFM/nutrient management strategies and the effect on crop performance, fallow management for recovery of soil fertility status, effect of manure application on soil organic matter fractions and soil health status and the like) have greatly contributed to our insight on how such technologies can be applied to improve the natural resource base within the context of the farming system. Studies into historical land management practices help to identify possible new technologies and practices (e.g. work on bio-char). In many ways these studies, apart from developing principles and concepts, are at the same time a test of technologies developed, like the high fertility trenches technology for hillsides. Investigation of the applicability of conservation agriculture in different systems has confirmed opportunities for introduction of no-till systems on the Colombian savanna Oxisols. Though the basic principles of conservation agriculture are known, their short and long-term effects on the natural resource base, and the applicability to different management systems (in Africa and elsewhere) need to be further investigated.

In relation to below-ground biodiversity (BGBD) and the role of soil organisms in maintaining soil fertility and sustaining agricultural production, the inventory of BGBD in many different benchmark areas has contributed significantly to our insights of what is actually there (including new species discovered) and the impact of changing land use and on the abundance and diversity of soil organisms belonging to various functional groups. The BGBD project has successfully concluded its first phase and a publication summarizing common standard methodologies for soil biodiversity inventory has been completed after validation across carefully selected benchmark sites in Brazil, India, Indonesia, Ivory Coast, Kenya, Mexico and Uganda. Continuing studies into the mechanisms by which soil organisms interact with the other biological components helps us to understand the role and function of these particular soil organisms (e.g. suppression of soil borne pest and diseases), as indeed a basis for developing biological technologies. Investigation of awareness and knowledge of farmers on soil organisms and their beneficial or harmful effects, help to develop management options, of which options for managing earthworm populations may be the most advanced.

Identification of appropriate indicators of soil quality has remained an elusive exercise because it has been complicated by the need to simultaneously address the multiple dimensions of soil function (i.e. ecosystem services), the many physical, chemical and biological factors controlling biogeochemical processes as well as their variability in space and over time. Intensive work with a large number of farmers groups in various locations in Africa and Central America has documented a diversity of rich, context-specific knowledge, priorities, and constraints of smallholders relating to soil fertility management. An innovative community-based learning strategy has successfully stimulated the growth of a "dynamic expertise" that combines local and outsiders' soil fertility management knowledge, and may be used elsewhere as a framework for interaction between farmers, scientists and extension workers with a view towards scaling this expertise up and out using local networks and institutions. Approaches and methodologies to integrate local and scientific indicators of soil quality aim to incorporate local demands and perceptions of soil management constraints as an essential input to relevant research for development activities as well as to empower local communities to develop soil quality monitoring and decision-making systems for better management of the soil resource. Farmers need early warning signals and monitoring tools to help them assess the status of their soil, since by the time degradation is visible and land productivity reduction evident, it is either too late or too costly to reverse it. Furthermore, the costs of preventing reductions in land productivity are often several times less than costs of remedial actions. Conventional approaches to land quality assessment have looked at the physical and/or chemical characteristics of the soil. More recent approaches, however, have included integrative measures like Near Infrared Reflectance Spectrometry-NIRS and biological measures to assess soil quality. Biological indicators have the potential to provide early warning because they can capture subtle changes in land quality as a result of their integrative nature that simultaneously reflects changes in physical, chemical and biological characteristics of the soil.

Progress towards achieving output level impact

- *Improved soil health and fertility contribute to resilient production systems and sustainable agriculture*

In Output 1, the physical, chemical and biological dimensions of soil research have been addressed. Nevertheless it is only in few cases when all dimensions have been studied in the same place and the same time in conjunction with labour and market constraints as proposed by the ISFM paradigm. Soil fertility decline is not a simple problem as it interacts pervasively over time with a wide range of other biological and socio-economic constraints to sustainable agroecosystem management. It is not just a problem of nutrient deficiency but also of inappropriate germplasm and cropping system design, of interactions with pests and diseases, of the linkage between poverty and land degradation, of often perverse national and global policies with respect to incentives, and of institutional failures. Tackling soil fertility issues thus requires a long-term perspective and holistic approach.

As indicated above much of the work on principles, concepts and methods to inform technology and system development does consider the contribution to resilient production systems and sustainable agriculture as well. To a certain extent these are implicit in the studies undertaken. The ex-ante studies that have been undertaken to evaluate the viability of proposed technologies address these concerns more explicitly. Monitoring and evaluation and impact studies are increasingly becoming an integral part of our research projects. Attention will be devoted to impact assessment, with a participatory nature, of the technologies introduced. For example, the work to identify and validate indicators of soil quality, including biological quality, using replicable methodology under smallholder conditions to support farmers' experimentation with soil fertility management options will feed directly into the impact assessment studies.