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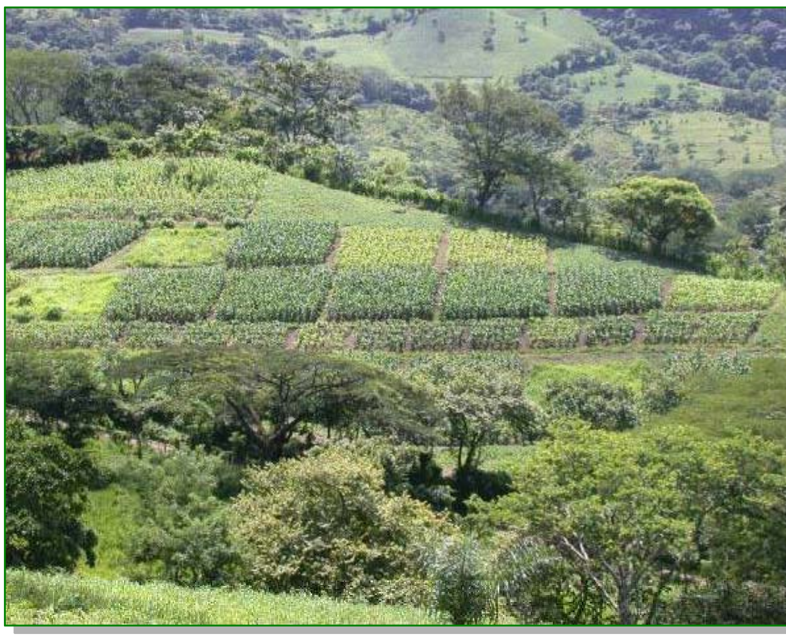

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TSBF Institute (PE-2 Project):
Integrated Soil Fertility Management in the Tropics

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4. RESEARCH OUTPUTS AND ACTIVITIES

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

Rationale

Sustainable agriculture is viewed 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 trascends the classical boundaries of the biophysical sciences and requires integration with economics, sociology, anthropology and political science.However, the rural poor are often trapped in a vicious poverty cycle with land degradation, fuelled by the lack of relevant knowledge or appropriate technologies to generate adequate income and opportunities to overcome land degradation.

Improving soil fertility is essential for intensification and diversification of cropping systems and the recuperation of degraded lands. Farmers in the tropics, particularly in Africa and few countries in Central America rely mainly on organic inputs to maintain or improve soil fertility, with small or no additions of inorganic fertilizers. Within the ISFM framework, it is now recognized that both organic and mineral inputs are necessary to enhance crop yields without deteriorating the soil resource base. This recognition has a practical dimension because either of the two inputs are hardly ever available in sufficient quantities to the small scale farmer, but it also has an important resource management dimension as there is potential for added benefits created by positive interactions between both inputs when applied in combination. Such interactions can lead to improved use efficiency of the nutrients applied in organic or mineral form or both. Assessing the combination of the two in terms of resource quality, nutrient input, C, N and P dynamics and water use efficiency help to identify technology options for increasing farm productivity and system resilience. 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 and confront these processes with the socio-economical dimensions of rural and urban communities.

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 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 upscaling 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.

Milestones

- By 2006, indicators of soil health and fertility at plot, farm and landscape scales identified.
- By 2008, practical methods for rapid assessment and monitoring of soil resource base status developed.
- By 2010, decision tools for soil biota, nutrient and water management developed and disseminated to stakeholders.

Highlights

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- Short-term mineralization data supported the existence of 3 classes of organic resources instead of the four originally proposed by the Decision Support System for organic N management, although threshold values for N, polyphenol, and ligning content were observed to be respected. However, organic resources also govern other functions, operating in the medium to long term, and for these functions, the original 4-class concept may be proven valid.
- Near Infra Red (NIR) spectrometry was observed to be a powerfull tool to predict decomposition and nutrient release characteristics of organic residues.
- Although soil organic matter (SOM) was responsible for 75 to 85% of the cation exchange capacity (CEC) of sandy soils, the biochemical composition of the organic inputs did not have an important effect on the CEC of SOM, invalidating one of the potential long-term benefits of managing organic resource quality.
- In Western Kenya, farmers managed their fields according to their perceived land quality, varying the timing and intensity of management practices along soil fertility gradients, while the internal heterogeneity in resource allocation varied also between farms of different social classes, according to their objectives and factor constraints.
- In Western and Central Kenya and Eastern Uganda, most of the variation in soil fertility status (organic C and available P content) of individual fields was observed at the farm level, exceeding that of the village and district level. Farmer's appreciation of these differences in soil fertility status between fields within a farm correlated very well with measurements of organic C and available P, taken together.
- A decision guide to integrate various food, feed and green manure legumes in various social and farm niches was developed and tested in Ethiopia, Kenya and Uganda. Other research and development partners have started to validate it in East African Region and beyond.
- Plant height measurements, taken at any moment after maize flowering, are a useful means to predict maize yield, using simple linear regression models.
- The lessons learned from the "Folk" Ecology project have been synthesized and summarized as a manual of interactive techniques. Rather than simply offering another "toolkit" for practitioners and farmers, the goal is to provide knowledge about the application of tools and methods developed and adapted under the project, highly relevant questions for scaling up the "Folk" Ecology approach to other projects and partners.
- Evaluation of water harvesting and input application revealed that while in Niger, the Zai technique was observed to significantly improve plant establishment and yields, in Kenya there was no significant effect of water harvesting on maize grain yield.

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- Showed that the plant measurements used to assess forage quality in animal nutrition studies can be used to predict aerobic decomposition of tropical legumes on the soil and confirmed the potential usefulness of IVDMD (in vitro dry matter digestibility) for screening tropical legumes for soil fertility management.
- High Mg^{2+} saturation caused marked negative effects in some soil physical properties of Vertisols such as: soil structure, rate of infiltration, saturated hydraulic conductivity and sorptivity. These changes have to be taken into account for developing improved soil management strategies.
- Showed that during the drying process, "magnesium soils" tend to reduce their volume, therefore causing negative changes in specific soil volume and normal and residual shrinkage. There was a reduction of soil volume equivalent to 28% when the soil dries from field capacity to wilting point.
- A description of *Martiodrilus* species with its main biological, ecological and functional attributes was made in native savanna and introduced pastures in Carimagua. Introduced pastures were a favorable media for this species.
- The impacts of the conversion of native ecosystems into extensive or intensive pastures on soil fauna were assessed. Extensive cattle ranching led to slight enhancement of earthworm populations, while fire induced a decrease in macrofaunal density.
- Found that there is genetic variability among accessions of *Brachiaria humidicola* regarding the nitrification inhibition (NI) activity of root exudates. The accession CIAT 16888 was identified as having superior NI activity compared with the commercial cultivar CIAT 679 used in most studies so far.
- Found that additions of charcoal to low fertility, acid Oxisols increases soil pH, cation exchange capacity and availability of various soil nutrients and result in a net increase in nitrogen fixation by common beans, measured by ^{15}N isotope dilution technique.

Activity 1.1 Improved understanding of soil biological processes regulating efficient nutrient cycling and organic matter dynamics

TSBFI-Africa

Partners

University of Zimbabwe, Harare, Zimbabwe; University of California, Davis, USA; Soil Research Institute, Kumasi, Ghana; Kenyatta University, Nairobi, Kenya; Katholieke Universiteit Leuven, Leuven, Belgium; Wageningen University, Wageningen, The Netherlands; Cornell University, Ithaca, USA.

Published Work

Cation exchange capacities of soil organic matter fractions in a Ferric Lixisol with different organic matter inputs

K. Oort, B. Vanlauwe and R. Merckx

Agriculture, Ecosystems and Environment, 2004, In Press

Soil organic matter (SOM) has an important effect on the physicochemical status of highly weathered soils in the tropics. This work was conducted to determine the contribution of different SOM fractions to the cation exchange capacity (CEC) of a tropical soil and to study the effect of organic matter inputs of different biochemical composition on the CEC of SOM. Soil samples were collected from a 20-yr old arboretum established on a Ferric Lixisol, under seven multipurpose tree species: *Afzelia africana, Dactyladenia barteri*, *Gliricidia sepium, Gmelina arborea, Leucaena leucocephala*, *Pterocarpus santalinoides*, and *Treculia africana*. Fractions were obtained by wet sieving and sedimentation after ultrasonic dispersion. Relationships between CEC and pH were determined using the silver thiourea-method and were described by linear regression. The CEC of the fractions smaller than 0.053 mm was inversely related to their particle size: clay (<0.002 mm) > fine silt (0.002-0.02 mm) > coarse silt (0.02-0.053 mm), except for the soils under *Treculia africana, Dactyladenia barteri* and *Leucaena leucocephala*, where the CEC of the fine silt fraction was highest or comparable to the CEC of the clay fraction. The clay and fine silt fractions were responsible for 76 to 90% of the soil CEC at pH 5.8. The contribution of the fine silt fraction to the CEC at pH 5.8 ranged from 35% to 50%, which stressed the importance of the fine silt fraction for the physicochemical properties of the soil. Differences in CEC between treatments for the whole soil and the fractions could be explained by the differences in carbon content. Except for the intercept for the clay fraction, SOM had a significant (at $P = 0.001$) contribution to both the intercepts (= estimated CEC at pH 0) and slopes (= pH dependent charge) of the CEC-pH relationships for the whole soil and the fractions. The CEC of SOM at pH 5.8 varied between 283 $cmol_c$ kg^{-1} C for particulate organic matter and 563 $cmol_c$ kg^{-1} C for the fine silt fraction. The biochemical composition of the organic inputs did not have an important effect on the CEC of SOM. In total, SOM was responsible for 75 to 85% of the CEC of these soils.

Assessment of labile phosphorus fractions and adsorption characteristics in relation to soil properties of West African savanna soils

O.C. Nwoke, B. Vanlauwe, J. Diels, N. Sanginga and R. Merckx

Agriculture, Ecosystemsn and Environment, 2004, In Press

The labile and moderately labile phosphorus fractions and adsorption characteristics of surface and subsurface horizons of eleven soil profiles in the derived savanna (DS) and the northern Guinea savanna (NGS) of West Africa were assessed. The labile P fractions are the resin and HCO_3 extracTable inorganic (Pi) and organic (Po) P. The moderately labile fractions are the NaOH extracTable portion of soil P in the Hedley sequential procedure. The resin P, considered the most readily available fraction, varied from 1 to 14 mg kg^{-1}, HCO_3-Pi ranged from 3.3 to 11 and HCO_3-Po was between 4 and 12 mg kg^{-1} in the surface horizons of the DS soils. In the NGS, the topsoil contained 1.5 – 3 mg kg^{-1} of resin P, 5 – 8 mg kg^{-1} of HCO_3-Pi, and 7.5 – 9.7 mg kg^{-1} of HCO_3-Po. Sodium hydroxide-Po was the largest of the fractions in all the soils studied. It ranged from 23 to 55 mg kg^{-1} in the topsoil. In general, the labile P levels were higher in soils of the DS than of the NGS and were related to the oxalate-extracTable Fe (Fe_{ox}), and Al (Al_{ox}) as well as soil texture. The subsoil of Kasuwan Magani (profile KS 9-21 cm) required 153 mg P kg^{-1} to maintain 0.2 mg P l^{-1} in solution (standard P requirement), and Danayamaka (profile DD 7-32 cm) required 145 mg P kg^{-1}. These could translate to 214 and 200 kg P ha^{-1} if a plough layer of 10 cm is assumed. Because these are within the plough layer, more P fertilizer would be needed for crop production than in the other soils. The standard P requirement and the adsorption maxima were related to Fe_{ox} and Al_{ox}, dithionite-Fe (Fe_d), and texture. The increase in labile P content with decreasing Fe_{ox} and Al_{ox} could imply that management practices capable of reducing the activities of Fe and Al in solution might improve P availability.

Modeling nitrogen mineralization from organic sources: representing quality aspects by varying C:N ratios of sub-pools

M.E. Probert, R.J. Delve, S.K. Kimani and J.P. Dimes

Soil Biology and Biochemistry. 2005. In Press

The mineralization/immobilization of nitrogen when organic sources are added to soil is represented in many simulation models as the outcome of decomposition of the added material and synthesis of soil organic matter. These models are able to capture the pattern of N release that is attribuTable to the N concentration of plant materials, or more generally the C:N ratio of the organic input. However the models are unable to simulate the more complex pattern of N release that has been reported for some animal manures, notably materials that exhibit initial immobilization of N even when the C:N of the material suggests it should mineralize N. The APSIM SoilN module was modified so that the three pools that constitute added organic matter could be specified in terms of both the fraction of carbon in each pool and also their C:N ratios (previously it has been assumed that all pools have the same C:N ratio). It is shown that the revised model is better able to simulate the general patterns on N mineralized that has been reported for various organic sources. By associating the model parameters with measured properties (the pool that decomposes most rapidly equates with water-soluble C and N; the pool that decomposes slowest equates with lignin-C) the model performed better than the unmodified model in simulating the N mineralization from a range of feeds and faecal materials measured in an incubation experiment.

On-farm testing of integrated nutrient management strategies in Eastern Uganda

A.O Esilaba, J.B. Byalebeka, R.J. Delve, J.R. Okalebo, D. Ssenyange, M. Mbalule, and H. Ssali. ***Agricultural Systems, 2005. In press***

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 profitably reverse nutrient depletion of their soils 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, agroforestry and livestock production. Farmers identified soil fertility constraints, 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 to other farmer groups working on integrated soil fertility projects, the farmer's designed eleven experiments for on-farm testing. One hundred and twenty farmers then chose, for participatory technology development, sub-sets of these eleven experiments, based on the main agricultural constraints and potential solutions identified and prioritized by the farmers. Quantitative and qualitative results from the testing, farmer evaluation and adaptation, training, dissemination strategies and socio-economic implications of these technologies are discussed.

The APSIM Manure Module: Improvements in Predictability and Application to Laboratory Studies
Probert, M.E., Delve, R.J., Kimani, S.K. and Dimes, J.P.
In: Delve, R.J. and Probert, M.E., ed., 2004. Modeling nutrient management in tropical cropping systems. ACIAR Proceedings No. 114, 136p.
Existing models are able to capture the pattern of N release from plant materials based on their C/N ratios. However, these models are unable to simulate the more complex pattern of N release reported for some animal manures, especially for manures that exhibit initial immobilization of N even when the C/N ratio of the material suggests it should mineralize N. This paper reports on progress towards developing a capability within the APSIM SoilN module to simulate nitrogen release from these manures. The SoilN module was modified so that the three pools that constitute added organic matter can be specified in terms of both the fraction of carbon in each pool and also their C/N ratios. The previous assumption that all pools have the same C/N ratio fails to adequately represent the observed behavior for release of N from some organic inputs. By associating the model parameters with measured properties (the pool that decomposes most rapidly equates with water-soluble C and N; the pool that decomposes slowest equates with lignin-C) the model performed better than the unmodified model in simulating the N mineralization from a range of livestock feeds and manure samples.

Testing the APSIM Model with Data from a Phosphorus and Nitrogen Replenishment Experiment on an Oxisol in Western Kenya
J. Kinyangi, R.J. Delve and M.E. Probert
In: Delve, R.J. and Probert, M.E., ed., 2004. Modeling nutrient management in tropical cropping systems. ACIAR Proceedings No. 114, 136p.
An experiment was conducted on an Oxisol near Maseno in western Kenya, to compare the growth of maize crops to inputs of two phosphorus sources. Commercial triple superphosphate (TSP) and Minjingu phosphate rock were applied either at a once-only rate of 250 kg P ha^{-1} or as five annual inputs of 50 kg P ha^{-1}. The experiment was carried out over 10 cropping seasons between 1996 and 2000. An additional factor studied was the source of N, either as urea or Tithonia biomass-N to supply 60 kg N ha^{-1}. Both N and P sources were applied only to the crops grown in the long rain season. The APSIM model has been tested against this data set. The effects of P treatments were large in the long rain season, but in the short rain season the inadequate supply of N greatly reduced growth and P effects. The yields of the maize crops were predicted well (r^2 = 0.88) with respect to both the P treatments (as TSP) and the N inputs (as urea). The predicted water, N and P stresses were informative in understanding the contrasting pattern of response observed in the two seasons. The simulation of this long-term experiment shows that the APSIM SoilP module is robust, in as much as it extends the testing of the model to a very different environment where there were both N and P stresses affecting plant growth, and on a very different soil type to where the concepts in the APSIM phosphorus routines were originally developed and tested.

Evaluation of a farm-level decision support tool for trade-off and scenario analysis for addressing food security, income generation and natural resource management
Robert J. Delve, Ernesto Gonzalez-Estrada, John Dimes, Tilahun Amede and Juma Wickama.
In: German, L. and Stroud, A., (ed.). Integrated Natural Resource Management in Practice: Enabling Communities to Improve Mountain Landscapes and Livelihoods. AHI Conference, 12-15 October, 2004. Nairobi, Kenya.
Resource-poor farmers face difficult decisions over the use of scarce nutrient sources in crop-livestock production systems. A better understanding of the comparative values and trade-offs in the use of land, labor, manures and other locally available resources is required in order to increase the production and efficiency of mixed crop-livestock systems. While efforts are required to expand our knowledge of the biophysical aspects of alternative uses of organic nutrient sources, similar efforts are also required on the socio-economic driving forces behind farmers' decision making. The approach uses trade-off analysis, partial budgeting and multiple goal linear programming to identify management options to address

farmers production criteria and overcome their constraints. This evaluation includes both the short and longer-term economic and environmental benefits. From the social and economic viewpoint, organic resources can be identified that could substitute for mineral fertilizers in areas where fertilizers are not affordable. From an environmental aspect, management practices could be identified that results in fewer nutrient losses and could rebuild or maintain the soil resource base. A multi-stakeholder coalition has been working in Ethiopia, Tanzania, Zimbabwe and Uganda and has successfully developed a decision support tool (DST) to explore these different trade-offs and scenarios based on smallholder farmers existing practices and opportunities. This paper uses case studies from AHI benchmark sites in Lushoto, Tanzania and Areka, Ethiopia to discuss the potential of the DST for improving farmers and development partners decision making to achieve food security, increase farm income, increase returns to land and labor and maintaining sustainable production. Examples to be presented will investigate scenarios and trade-offs for three different wealth categories per site and for different areas of the farm with varying soil fertility levels, for example:

- Land allocation – which crops to which land
- Efficiency of fertilizer use – when to apply, where to apply it in the rotation, how much
- Labor constraints – when to weed, when to apply manures
- Investment options: capital allocation-livestock versus crop enterprises, labor allocation-farm and non-farm
- Appropriate use of crop residues in mixed systems
- Integration of legumes into the system

The distribution of phosphorous fractions and sorption characteristics of benchmark soils in the moist savanna zone of West Africa

O.C. Nwoke, B. Vanlauwe, J. Diels, N. Sanginga and O. Osunubi

Nutrient Cycling in Agroecosytems, 2004, In Press

The fractionation of soil P into various organic and inorganic pools with differing levels of bioavailability coupled with the knowledge of the P adsorption and desorption characteristics of the soils provide insights into management strategies that might enhance availability to crops. Sequential soil P fractionation (using the modified Hedley scheme) was conducted on 11 soil profiles selected from the benchmark areas of the West-African moist savanna zone. Also P fractions were determined on soil samples taken from experimental fields under different management practices in the study area. Phosphorus adsorption and desorption studies were conducted on samples from the surface horizon of the soil profiles. The total P content varied within and among the soil profiles and tended to decrease with increasing depth in most cases. It varied from 53 to 198 mg kg^{-1} in the topsoil and about 30% existed in the organic form. The resin P fraction of the topsoil ranged between 1 and 14 mg kg^{-1} decreasing with depth within the soil profile. The low resin P levels indicate low availability. Addition of organic matter (OM) and soluble phosphate fertilizer (PF) increased the inorganic P (Pi) fractions extracTable with resin, HCO_3 and NaOH by about 400% in the northern Guinea savanna (NGS) fields but had no significant effect on the organic P (Po) pools and the more sTable Pi forms. Organic matter and PF alone or in combination (OM+PF) did not influence the Pi fractions differently in Glidji. The P sorption capacities were low with the adsorption maximum deduced from the Langmuir equation ranging from 36 to 230 mg kg^{-1}. The amount of P sorbed to maintain 0.2 mg l^{-1} in solution ranged between 0.6 and 16 mg kg^{-1}. Phosphorus desorption with anion exchange resin differed among the soils with the recovery of added P ranging from 17 to 66% after 96 h. On the average, more of the applied P was recovered in the DS soils than in the NGS soils. Because of the relatively low sorption capacity and the relatively high percentage recovery, small additions of P to most of the DS soils tested might be adequate for crop growth.

Performance evaluation of various agroforestry species as short duration improved fallows for enhancement of soil fertility and sorghum crop yields in Mali

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The human population growth rate in the Sahel (nearly 3% per annum) is among the highest in the world creating a high land use pressure with the disappearance of the traditional fallow system. This has accelerated the degradation of the natural resources base by a poverty-stricken population forced to overexploit soils, rangelands and forests in order to subsist. The consumption of mineral fertilizers in SSA increased slowly by 0.6% during the last 10 years, compared to 4.4% in the rest of the other developing regions. The total annual nutrient depletion in SSA is equivalent to 7.9 Mg yr-1 of N, P, and K, six times the amount of annual fertilizer consumption in the region. In the particular case of the southern Mali region, N-K-Mg budgets in 1992 were estimated to be -25, -20, and -5 kg per hectare per year indicating that as much as 40% to 60% of the income generated by farming in this region were based on "soil mining". It is in the light of these constraints that the Malian agricultural research institute (Institut d 'Economie Rurale, IER), the Sahel Program of the World Agroforestry Centre (ICRAF) and the International Crops Research Institute for the Semi Arid Tropics (ICRISAT) joined efforts to undertake research activities aimed at sustainably improving soil fertility and agricultural crop yields in the Mali. Thus, from the year 2000 14 different trees and shrubs are being tested in improved fallow systems to find which ones perform best to replenish soils and improve crop yields. The results have i) identified most suited species for 1 or 2 yr improved fallows, ii) determined their impact on sorghum grain yields and iii) documented the remnant effects of their impact on soil fertility and crop yields. Some species could not survive more than 1 year the Samanko conditions. In 2002, the first year of cultivation, it was the Kenyan provenances of Sesbania sesban which performed best with sorghum yields over 2 t ha^{-1}. A year later, 2003, there has been a general decrease in crop yield. Again, the Kenyan provenances of S. seban, with yields 40% lower than the first year of cultivation, were the worst affected by this decrease. No significant changes were observed in the traditionally tested chemical soil parameters.

Characterisation of soil degradation under intensive rice production in Office du Niger zone of Mali

M. Bagayoko, M.K. N'Diaye; M. Dicko and B. Tangara
Food security is a major priority of the most Sahelian governments. With the cyclic droughts, irrigation is believed to achieve that objective. Unfortunately, present observations show that soils of irrigated areas in Sub Sahara African countries have changed unfavourably. In the Office du Niger zones, producers and extension workers are concerned with soil degradation symptoms such as salinisation / alkalinisation or sodisation. For some people, this needs more attention while other think that the phenomenon is localised and therefore not very important. In the context of intensive crop production, from 1995 to 1999, "the Pole regional de recherche sur les Systèmes Irrigués (PSI)" which was a regional networking project was aimed to determine the nature, and the importance and dynamic of the processes in general and their effect on the evolution of soil fertility in particular. Analysis of the functioning of water Table has been made at different scales in the irrigated zones to explain the operation of the hydraulic system of the soil and estimated the in and out flow of water. More over, the study addressed the terms of hydro-saline balance. A piezometric network installed in the area revealed the impact of cropping systems and soil types on the evolution of water Table in terms of dynamics and quality. The results clearly show evidence of soil geochemical changes and water management of the irrigated areas. The present paper highlight the research conducted to combat soil degradation in the irrigated rice system in the Office du Niger in Mali from 1995 to the present days.

Mineral fertilisers, organic amendments and crop rotation managements for soil fertility maintenance in the Guinean zone of Burkina Faso (West Africa)

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Low nutrient contents in particular N and P deficiencies, low organic carbon content are the main characteristics of dominated Alfisols of the Guinean zone of Burkina Faso (West Africa). Long-term cultivation without or with low quantities of mineral fertilisers due to weak incomes of small holder farmers leads to soil fertility declining over years. Management options using mineral fertilisers, organic amendments, crop rotations with fallow and N2-fixing legume crops are discussed using results of agronomic experiments. Optimum crop yields are usually abstained by combination of mineral and organic fertilisers. Positive interactions between mineral and organic N have been pointed out, indicated that management options using both mineral and organic fertiliser could increase crop yields and allowing a sustainable management of soil fertility. Crop rotation with one year fallow could be an usable management option for soil fertility maintenance. Soil of annual fallow prevents soil organic carbon declining. But highest crop yields are usually achieved when legume crops such as groundnut or cowpea were used in rotation systems. Legume crops increase soil mineral nitrogen and N fertiliser use efficiency and both sorghum and cotton produced highest in Cotton-Sorghum-Groundnut rotation. Then, sustainable management of soil fertility can be achieved by integrated management of mineral and organic fertilisers in combination with crop rotations. N2-fixing legume crops (cowpea and groundnut) could be efficiently used to increase soil fertility and system productivities. Cotton-Sorghum-Groundnut rotation is one of the most efficient rotations for crop productivities increasing and soil fertility maintenance using mineral fertilisers at recommended doses for each crop. For a better productivity of the system, cattle manure need to be applied at 3 tonnes per hectare on sorghum and cotton.

Intensity of cultivation induced-effects on Soil Organic Carbon Dynamic in the western cotton area of Burkina Faso

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Soil organic carbon (SOC) dynamic is a key element in savannah soil fertility and much depends on farming systems. In the western part of Burkina Faso, the land use is greatly linked to the cotton-based cropping systems. These practices induced modifications of the traditional shifting cultivation and upgraded the issue of soil fertility management. In order to more understand its depletion process in this area, SOC dynamic was assessed based on a large typology of land cultivation intensity at Bondoukui (11 ° 51' N, 3° 46' W, altitude 360 m). Thus, 114 plots were sampled on soil 0 – 15 cm depth, considering the field-fallow successions (shifting cultivation, cyclic cultivation, continuous cropping), the age of each cultural phase, the tillage intensity (occasional ploughing, biennial ploughing, annual ploughing), and the soil texture (sandy and silty-clayey soils). Soil organic carbon physical fractionation was done according to the following particles size classes: > 200 µm; 50-200 µm, 20-50 µm and < 20 µm. The results exhibited an increase of SOC content, and a lower depletion rate with the clay content. After a long-term fallow, the land cultivation led to an annual loss of 2 % (315 kg ha^{-1}) of its organic carbon during the first twenty years. The different fractions of SOC content are affected by this depletion according to the cultivation intensity. The coarse SOC fraction (> 200 µm) was the most depleted. The organic matter (manure, crop residues) ploughing-in in low frequency of tillage system lowered soil carbon loss compared to annual ploughing. Nowadays, human-induced disturbances (wildfire, overgrazing, fuel wood collection, fallow duration decreasing, crop duration increasing) in savanna land unable fallow to reach the SOC level of previous equilibrated shifting cultivation system.

Nitrogen fertilizer equivalencies of organics of differing quality and optimum combination with inorganic nitrogen source in Central Kenya

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Nutrient Cycling in Agroecosystems 68: 127–135, 2004

Decline in crop yields is a major problem facing smallholder farming in Kenya and the entire Sub-Saharan region. This is attributed mainly to the mining of major nutrients due to continuous cropping without addition of adequate external nutrients. In most cases, inorganic fertilizers are expensive hence unaffordable to most smallholder farmers. Although organic nutrient sources are available, information about their potential use is scanty. A field experiment was set up in the sub-humid highlands of Kenya to establish the chemical fertilizer equivalency values of different organic materials based on their quality. The experiment consisted of maize plots to which freshly collected leaves of Tithonia diversifolia (tithonia), Senna spectabilis (senna) and Calliandra calothyrsus (calliandra) (all with % N >3) obtained from hedgerows grown ex situ (biomass transfer) and urea (inorganic nitrogen source) were applied. Results obtained for the cumulative above ground biomass yield for three seasons indicated that a combination of both organic and inorganic nutrient source gave higher maize biomass yield than when each was applied separately. Above ground biomass yield production in maize (t ha-1) from organic and inorganic fertilization was in the order of senna+urea (31.2), tithonia+urea (29.4), calliandra+urea (29.3), tithonia (28.6), senna (27.9), urea (27.4), calliandra (25.9), and control (22.5) for three cumulative seasons. On average, the three organic materials (calliandra, senna and tithonia) gave fertilizer equivalency values for the nitrogen contained in them of 50%, 87% and 118% respectively. It is therefore recommended that tithonia biomass can be used in place of mineral fertilizer as a source of nitrogen. The high equivalency values can be attributed to the synergetic effects of nutrient supply, and improved moisture and soil physical conditions of the mulch. However, for sustainable agricultural production, combination with mineral fertilizer could be the best option.

Completed Work

Resource flows and nutrient balances in smallholder farming systems in Mayuge district, eastern Uganda

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Agroecosystems and Environment, 2005, Revised article submitted

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. Resource flow mapping was conducted during a participatory learning and action research (PLAR) process. The resource flows were transformed into nutrient flows and partial nutrient balances were calculated for the crop production, animal production, household and out of farm systems 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, 10 % were average soil fertility managers (class II) and 87% were poor soil fertility managers (class III). There was a strong relationship between wealth ranking according to the farmers' own criteria and soil fertility management classification. Soil chemical and physical properties of the soils in the three soil fertility management classes did not differ significantly despite the differences perceived by the farmers. The study revealed that very low quantities of resources and nutrients enter the farm system, but substantial amounts leave the farm in crop harvests. The main source of nutrients on the farm is the crop production system and the major destination is the household system. The livestock component contributed little to the flow of nutrients in the farm system due to the low levels of livestock ownership. The results indicate that the net farm nutrient balances kg ha^{-1} per season for all the nutrients (N, P, and K) were negative for both the

good and the poor soil fertility managers. Class 1 farm balances irrespective of the season, were however more negative than those of class 3 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} $year^{-1}$, while for the short rains seasons (SR 2000 and 2001), the nutrient balances were –3.5, - 0.5 and -6.0 kg ha^{-1} $year^{-1}$ 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} $year^{-1}$ while for the short rains seasons (SR 2000 and 2001), the nutrient balances were –3.5, 0.5 and –5.0 kg ha^{-1} $year^{-1}$ respectively. The partial nutrient balances for the various subsystems in the short rains for class 1 farmers were lower than those of the long rains season. Significant nutrient loss occurred in the crop production system as almost no nutrients return to the system. Potassium export from the farm was severe especially for farmers who sell a lot of banana. 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. Strategic management of nutrients that enter the household system such as through home gardening and composting near the household would greatly increase the return of nutrients to the crop production system.

Mineral nitrogen contribution of Crotalaria grahamiana and Mucuna pruriens short-term fallows in eastern Uganda

J.B. Tumuhairwe, B. Jama, R.J. Delve, M.C. Rwakaikara-Silver.

African Crop Science Journal, in review

Nitrogen (N) is one of the major limiting nutrients to crop production in Uganda and is depleted at faster rates that replaced. Consequently, yields at farm level are less than 30% of the expected potential. Paradoxically, the majority subsistence farmers are poor to afford use of mineral fertilizers but improved fallow have been reported economically feasible in such conditions. Therefore, a study was initiated in Tororo district, eastern Uganda (i) to determine mineral N contribution of *C. grahamiana* and *M. pruriens* short-duration fallows compared with farmers' practices of natural fallow, compost manuring and continuous cropping, (ii) sampling period that closely related to maize grain yield was also determined and also (iii) whether improved fallow provided adequate mineral N for optimum grain yield compared to farmers' practices. It was noted that improved fallows increased mineral N at Dina's site during fallowing (at 0 week sampling), and in the first and fifth week after incorporating their biomass than farmers' practices. For instance, at harvesting fallows (0 week sampling), *C. grahamiana* and *M. pruriens* had 12.68 and 12.97 mg Kg^{-1} N compared to 6.79 and 7.79 mg kg^{-1} N from following natural fallow and continuous cropping respectively. However, no significant increase was realized at Geoffrey's site at any of the sampling dates attributed to low biomass yield and incorporated. *C. grahamiana* increased grain yield by 29.3% (Dina's site) and 56.6% (Geoffrey's site) and *M. pruriens* by 36.0% (Dina's site) and 27.2% (Geoffrey's site) compared to natural fallow with -11.9% (Dina's site) and 17.4% (Geoffrey's site) then compost manure -9.6% (Dina's site and 0% (Geoffrey's site) in relation to continuous cropping as a bench mark. Supplementing the land use systems LUS (*C. grahamiana*, *M. pruriens*, natural fallows, compost manure and continuous cropping) with inorganic N fertilizer as urea significantly increased grain yield in all except *C. grahamiana* at both sites. There were two peaks on mineral N. The first and major peak occurred in the third week dominated by NO_3^--N and the minor one in the tenth week with NH_4^+-N prominent consistent at both sites. Mineral N in the fifth week after incorporating biomass was most closely related to grain yield followed by sampling at planting (0 week).

Mucuna pruriens and Canavalia ensiformis legume cover crops: Sole crop productivity, nutrient balance, farmer evaluation and management implications

R.J. Delve and B. Jama

Afrcian Crop Science Journal, in review

The high costs of inorganic fertilizers in Uganda limits their use by resource-poor smallholder farmers. There is also little practical knowledge existing in Uganda about the management of herbaceous legume cover crops that often are promoted as low-cost alternatives. Therefore, the effects of a one season sole-crop fallow of *Mucuna pruriens* and *Canavalia ensiformis* legume cover crop on a following maize crop and topsoil N, P and K balances were assessed for 2 seasons in two locations, Osukuru (0° 39′ N, 34° 11′ E) and Kisoko (0° 43′ N, 34° 06′ E) of Eastern Uganda. During land preparation, 50 or 100% of the aboveground biomass of Mucuna and Canavalia was manually incorporated into the topsoil (0 to 15 cm depth) using a hand hoe. Mucuna and Canavalia aboveground biomass production was not affected by the initial soil fertility of the sites and produced 6 t ha^{-1} at Osukuru and 7 t ha^{-1} at Kisoko. Incorporation of 50% or 100% of the *in-situ* aboveground biomass significantly increased maize grain by up to 118% and stover yields by up to 75% compared to farmer practice in the first season after incorporation in nearly all treatments. No significant increases in maize grain or stover yields were observed in the second season after application. No significant differences were also observed between 50% and 100% *in-situ* biomass incorporation on maize grain and stover yields, giving resource poor farmers the option of alternative uses for the additional 50% of the biomass, for example, biomass transfer to other parts of the farm, for compost making or for livestock feed. In the first season after incorporation of the legume cover crops, addition of 100% and 50% of the aboveground biomass resulted in a positive nutrient balance for N only. Additions of 100% of the aboveground biomass of either Mucuna or Canavalia were needed for a positive nutrient balance for K, whereas none of the treatments produced a positive balance for P, thus suggesting the need for inorganic P fertilizers additions in order to mitigate depletion in the long run. Farmers had multiple criteria for assessing the different species and used these to select the potential species that fitted within their production systems and production objectives.

On-going Work

Relationships between organic resource quality and the quantity/quality of the soil organic matter pool

H Wangechi and B Vanlauwe

The management and enhancement of Soil Organic Matter (SOM) is pivotal to the sustainable utilization of soils. SOM is a major determinant of soil fertility, water holding capacity and biological activity and is highly correlated to levels of above and below ground biodiversity. A loss of SOM can lead to soil erosion, loss of fertility, compaction and general land degradation. In addition changes in the use and management of soils that result in a decline in SOM can lead to a release of CO_2 to the atmosphere, with practice that increases SOM leading to sequestration of C from the atmosphere to soils. The management of SOM is therefore important at the field, regional and global scale. Management practices that affect crop biomass production, residue maintenance, and litter will also affect SOM.This report summarizes the progress of an ongoing project in central Kenya (Embu and Machanga) sites. The main objective focuses on the role of the quality and/or quantity of organic resources in sustaining crop production and regulating the quality and quantity of the SOM pool under different soil and climatic conditions. Similar experiments are being undertaken in Ghana and Zimbabwe. The impact of these organic resources on crop yields, N use efficiency, and SOM dynamics are being monitored over time in these sites.

Summarizing the last 5 seasons in the Kenyan sites, maize yields were influenced significantly by the application of organic materials, their organic resource quality, and fertilizer nitrogen application (Figure 2a). Grain yields were highest for Tithoniaand and Calliandra for both Embu and Machanga sites. In Embu, application of maize stover, manure, and sawdust resulted in higher yields compared to the control plots, while in Machanga, this was true for the manure treatment. In the latter site, application of maize stover and sawdust in absence of fertilizer N depressed maize yields. Generally spoken, responses to application of N fertilizer were minimal in Embu for most organic resources while in Machanga, application of N fertilizer substantially increased grain yields for all organic inputs, except manure (Figure 2b).

With last year's approval of the National Science Foundation grant on 'The interaction between resource quality and aggregate turnover controls ecosystem nitrogen and carbon cycling', it will be possible to look at the quantity and quality of biologically meaningful SOM pools, following a size-density fractionation procedure after aggregate separation. Isotopes will be used to trace the contribution of freshly applied and old organic C to the various SOM pools. The latter information will reveal insight in how aggregate turnover is affected by the resource quality of the applied organic resources. It will also be possible to look quantify N_2O production as this counteracts the potential sequestration of C due to its relatively high global warming potential. Finally, attempts will be made to directly quantify the fate of applied fertilizer N as affected by mixing this input with organic resources of varying quality, using ^{15}N labeled fertilizer. The experiments are expected to continue for at least 5 more years as their final goal is to make conclusive statements regarding the management of organic resource quality as a potential means to regulate the SOM quantity and quality and consequently the various functions associated with this.

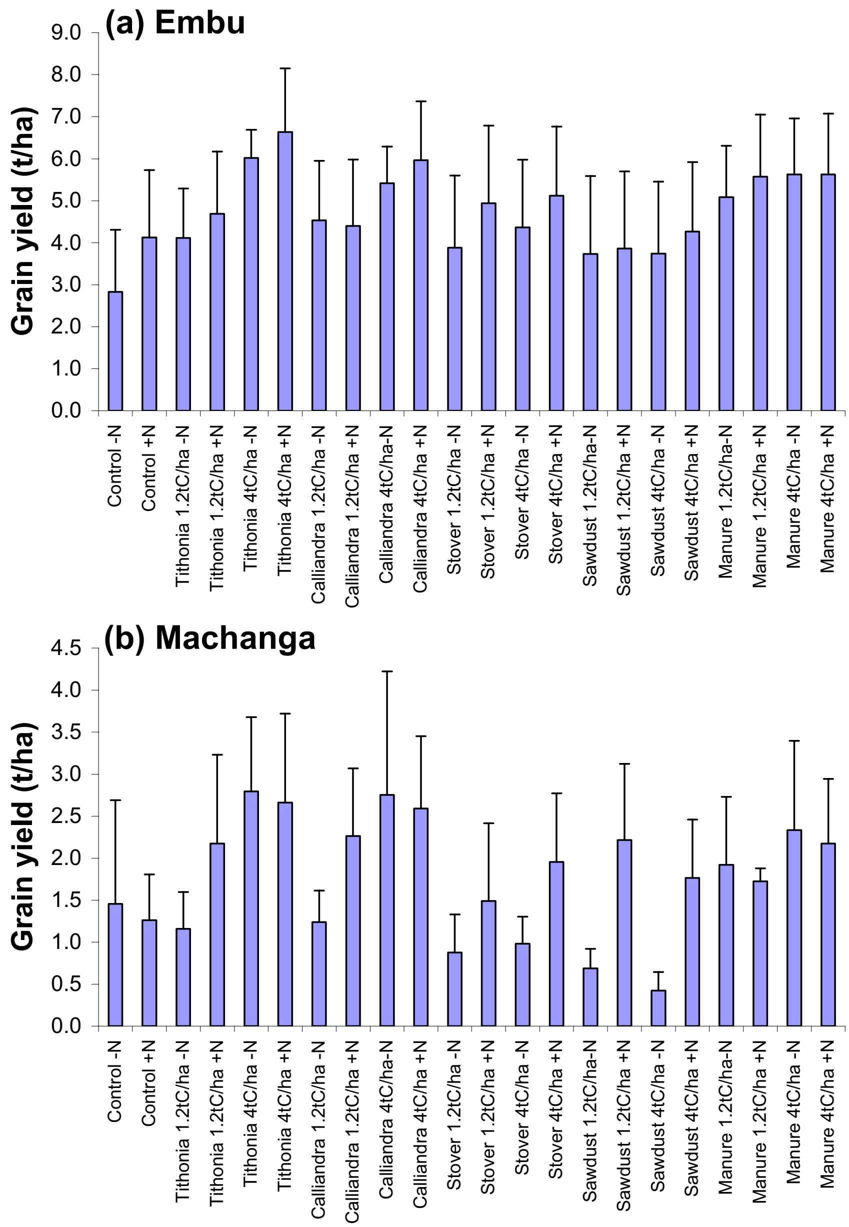

Figure 2. Maize grain yield as affected by application of organic resources of varying resource quality and/or mineral N fertilizer. Data presented are average values over 5 cropping seasons. Error bars are standard deviations.

Developing a decision support tool for evaluation of trade-offs and scenario analysis, results of a collaboration between ILRI, ICRISAT, TSBF and national partners

A decision support tool for evaluating alternative nutrient sources, management practices and impacts on soil fertility has been developed and evaluated. This has successfully developed a linked Decision Support Tool (DST). The DST has two components, a data entry and database section and a multiple goal linear programming tool. It was not thought necessary to link simulation models explicitly as their data can be added into the DST for evaluating trade-offs and scenarios. For this work, an approach established by the International Livestock Research Institute (ILRI), to analyze agricultural systems at the farm level was followed. The core component of this approach is the integration of simulation and multiple-criteria optimization models. Both data and models are assembled in the software, IMPACT (integrated modeling platform for animal-crop systems). The methodological aspects of IMPACT and its interaction with optimization models are briefly described below and given in Figure 3. IMPACT provides a protocol for collecting essential data to characterize a farming system. This data collection protocol is organized in such way that it describes the flow of resources through all the farming activities and their interactions. Information within IMPACT is organized in eight groups: 1) climate; 2) family structure; 3) land management; 4) livestock management; 5) labor allocation; 6) family's dietary pattern; 7) farm's sales and expenses; and 8) soil nutrient flow. In addition, IMPACT processes these data to provide a baseline analysis of the system's performance. This base-line analysis includes: 1) monthly financial balances; 2) the family's monthly nutritional status; and 3) an annual soil nutrient balance.

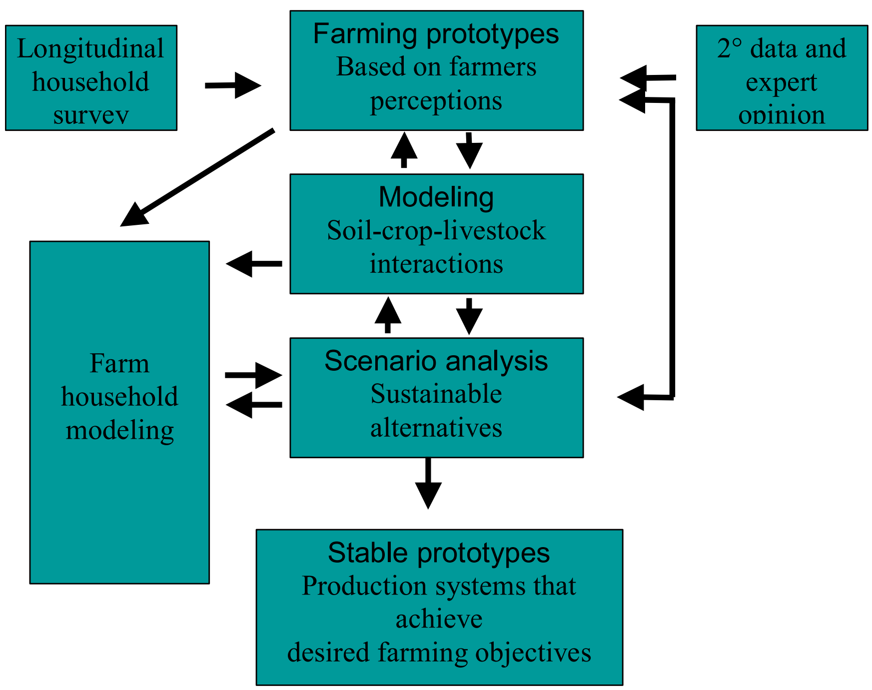

Figure 3. System prototyping and impact assessment for sustainable alternatives in mixed farming systems in high potential areas of East Africa (Ref: M. Waithaka, P. Thornton, H. Booltink, K. Shepherd, R. Kaitho, W. Thorpe and B. Salasya, 2002).

A suite of simulation and optimization models can be directly linked to the data stored in IMPACT. In IMPACT's current version (1.0.3), there is direct connectivity with the Household optimization model and the Ruminant simulation model. The Household model is a multiple-criteria model for assessing the impact of management interventions on the performance of farming systems and the livelihoods of the families that depend on them. The model explicitly incorporates IMPACT data related to on- and off-farm resources, as well as their seasonal management. It also includes information on food security-related factors, off-farm income generation, and labor constraints. Thus, the Household model determines the best combination of farm resources that satisfy a set of objectives according to a series of both management and economic interventions. These objectives can be directed towards maximizing gross margins, minimizing nutrient losses, or minimizing risk, amongst others. The effect of interventions can be tested by including simulated outputs from other models (e.g. the Ruminant model mentioned above and DSSAT). Thus, the overall effect of a specific intervention is subsequently tested at the whole farming system level by including simulated outputs in the Household model.

The DST captures all inputs and outputs for the farm enterprise, especially in terms of labor and cash spent on buying food and household items throughout the year. A major advance in this work was achieved when labor was separated by individual operation within crop and livestock management, e.g. for land preparation, planting, fertilizing, weeding etc. This gives the DST the power to be able to add in different scenarios easily, for example, if you wanted to see what difference adding more fertilizer to a crop would make, a soil-crop model could be used to give a 20 year average yield and in the DST another enterprise can be added to reflect this fertilizer use. As labor and cost are already known for most of the operations in this crops production, another scenario is very quick to add.

Legume green manuring for soil productivity improvement in eastern Uganda
M.J. Kuule, M.A. Bekunda and R.J. Delve.
Paper in preparation from Masters thesis
Declining per capita food production has been blamed on continuous cultivation of the land resource without adequate replenishment of soil nutrients. A recent fertilizer use survey reported a less than 1kg of nutrient fertilizer per hectare per year. Yet rates of nutrient uptake by plants through crop harvest or loss through leaching and other loss processes from arable land are much higher. This leads to serious nutrient depletion. Green manuring offers an alternative source of nutrients especially N in a relay system of intercropping. A study to demonstrate this potential and to identify suiTable legume species for the area was conducted on farmers' fields in two sub counties, Kisoko and Osukuru in Tororo district. Four legume species, *Canavalia, Crotalaria, lablab* and *Mucuna*, were intercropped with Maize (Longe 1variety) in the first season (short rains of 2000) on plots of 5m X 5m. The legumes were incorporated during land preparation for the second season, in their respective plots and planted with maize. Maize grain and stover yields were measured for each season and an economic analysis using partial budgeting and marginal rate of return tools performed to highlight the feasibility of the green manure technology in the farming system. Results showed a no significant response in the intercropping (first) and third (residual) seasons, but significant maize gain yield increase for Crotalaria and Lablab green manure after incorporating(second season) the legumes of 96.4 and 69.6 % respectively compared to the control plot. This was probably due to deep nutrient capture by the Crotalaria roots and recycling the nutrients through leaf fall. Economic analysis results indicated positive returns to both land and labor from using green manure technology and highest Marginal rate of return of 100.63%were obtained from using *Mucuna* compared to *Canavalia* green manure. Based on economic returns and ease of establishment, *Mucuna* and Canavalia green manures were recommended for farmers as low cost soil improving technology.

AfNet: The role of micro organisms in African farming systems

Site 1: Cameroon

Arbuscular Mycorrhiza Resource Bank and Selection of Beneficial Microorganisms for Crop Production in Cameroon Acidic Soils
The new concepts on food production favours an integrated approach based on a significant reduction in the excess use of chemical products for more sound ecological ones. Our overall goal in this project is to

promote an ecological approach in agricultural systems and the integrated management of land resources for the enhancement of productivity and agro-ecosystem sustainability. Soil biota can be manipulated to enhance nutrient cycling, improve the physical properties of soil and regulate decomposition processes. Key soil biotic groups such as N-fixing bacteria, mycorrhizal fungi, earthworms and termites are important regulators for nutrient cycling and good soil physico-chemical properties. The Applied Microbiology & Bio-fertiliser Unit (UMAB) is developing biological processes in Cameroon. A project set up by UMAB for the production and marketing of two microbial fertilisers. N-fixing bacteria may accelerate natural fertilisation of soil through atmospheric nitrogen fixation in the root nodules of legumes such as groundnut. Mycorrhizal fungi are useful for soils' natural fertilisation, improving phosphorus cycling, protecting crops against some diseases and pests or drought. Bio-fertilised crops and trees have some additional characteristics such as: a better growth and vigour, fast production, yield improvement, reduction of losses caused by diseases, pests or transplantation, products of better quality and are also better adapted to poor soil conditions. Most field assessment in Oxisol, Ultisol and Vertisol showed significant increase in growth, yield (50 to more than 200 %), diseases tolerance and also food quality after using the bio-fertiliser inoculation technology (rhizobia or mycorrhiza).

Nutrient cycling by AM and legume cover crop: potential for crop production in sub-Sahara acid soils

This is collaborative work between institutions in six AfNet Sub-Saharan African countries. The aim of the project is to assist small scale farmers in these countries to improve their agricultural production systems and profitability by introducing ecologically sound and sustainable mycorrhiza bio-fertiliser technology. The specific objectives of the project are to: 1) Initiate an arbuscular mycorrhiza fungi resource bank and select beneficial micro-organisms, 2) Assess the effectiveness of mycorrhizal inoculation using legume cover crops for biomass production, N and P cycling and soil fertility, 3) Quantify the impacts of legume cover crop on maize and legume yield. 4) Evaluate the potential of mycorrhiza on soil microbial activities and disease tolerance. 5) Create awareness, assess socio-economic benefits at farmers' level. 6) Build capacity on mycorrhizal technology through training. The work will be conducted in different agro-ecosystems in six Central, East, and Southern African countries on acid soils. The project will provide post graduate training in soil biological management and sustainable agriculture. In addition, good quality mycorrhizal bio-fertiliser are expected to be mastered during the project. The research is thought to provide scientific understanding of the functioning of key soil organisms and their potential for a better crop production management and also improve capacity building. Through participatory approach, awareness will be created, and farmers' socio-economic status will be improved. In addition, reports, workshops, brochures, and policy briefs and methods for legume micro-symbionts management to sustainable soil fertility and food quality will be recommended. It is thought that network collaboration among scientists interested in the biology and fertility of tropical soil management will be developed.

Establishment of Arbuscular mycorrhiza fungi resource bank and selecting beneficial micro-organisms

An important microbial resource bank of beneficial organisms was set up. The beneficial organisms are: mycorrhizal fungi, rhizobia, and pseudomonad. Recently a new group, phosphorus solubilising micro-organism (PSM) was added to the previous ones. The arbuscular mycorrhiza fungi (AMF) collection was set up from more than 200 soil samples collected in diverse agro-ecological zones of Cameroon (much more on humid forest acidic soils). Results from systematic sampling on land use systems (forest, fallow, plantations and farm soils) showed that direct evaluation on mycorrhizal diversity from spores is generally an underestimation. Trapping and repetitive sampling may be the best way to obtain a good evaluation of soil diversity of AMF species. More than 230 isolates of Glomalean fungi constitute the AMF resource bank, from which only about 50 % of isolates are identified (40 species) at species level and most at genus level using morphological methods. Non identified isolates could lead to new species. Their distribution is as follows and contains 5 genus out of 6 known in the world: *Glomus* (73%), *Gigaspora* (14%), *Acaulospora* (6%), *Scutellospora* (4%), *Sclerocystis* (3%). The most distributed species are *Glomus aggregatum*, *Glomus clarum* and *Glomus versiforme*. From this collection, only 22 isolates were screen for their efficiency for crop improvement. In order to have a good inoculum for large scale evaluation, it is useful to follow up successive steps such as: isolates characterization (root colonisation, spore number, infectivity,..), selection (plant growth increase, P & N uptake, mycorrhizal dependancy, yield, stress and disease tolerance, competitivity) before production at pilot scale. After this step, the inoculm produced on sterile substrate must be evaluated for biomass and yield improvement under nursery and latter on farm conditions using specific crops. Also inoculum viability and efficiency should be checked during storage (1 to 3 years) in order to assess the best storage conditions and the loss on activity during storage and time. A strategy of inoculum improvement was set up by a regular selection of the best mixture of strains. Preliminary isolation from 16 acid soils samples originating from 8 sites and 4 provinces (out of 10 in the country) under oil palm rhizosphere provided 230 isolates of PSM. The P solubilising activity were assessed under Petri dishes but a more complete characterisation and identification of some strains is envisaged. Most isolates are microscopic fungi and rhizobacteria (*Pseudomonas, Bacillus*).

Arbuscular mycorrhizal fungi studies

As one of the main research theme, advanced studies were carried out to set up a good inoculum for the nutrient cycling using legume cover crop project on acid soils. Soils from natural habitat (farm, fallow and forest) in more than 85% sites studied contain less than 10 spores/g soil. In some cases, this number may reach 48 to > 100 spores/g in farm soils but in few cases the number can be as low as 0 to 5 spores/g soil. AMF studies also include diversity, morphological characterization of mycorrhizal spores and roots, physiological characterization of their infectivity, viability during storage, root colonization, root growth parameters, enzymatic activities, P and N uptake, plant biomass and yield increase under nursery or farm conditions.

AMF characterization from soil samples

The number of infectious propagules (MPN test) from 5 soil sites (Bafia, Douala;, Edéa-Ndupe, Ngaoundéré and Yaoundé) reveal a very high variation from one site to another. This number varied from 0.3 for Edéa-Ndupe forest soil, 5 for Douala farm soil, 17 for Bafia fallow soil, 43 for Yaoundé farm soil and 2783 for Ngaoundéré mixed farm and cattle rearing soil. This variation was also noticed on millet root colonization by the same soils from 25% (Edéa-Ndupe soil) to 98% (Ngaoundéré soil). No correlation was found between spore number and the number of infectious propagules. Another study to establish the influence of land use system (LUS) on AMF diversity microbial biomass was done on forest, fallow, plantations and farms in humid forest zone of Cameroon. The results will be available at the end of this cropping season.

Selection and inoculum production

This study was carried out using cowpea, leek and millet under controlled conditions. Results shown in Table 1 indicate that out of 10 isolates, the most effective isolates for root colonization for cowpea are GIMNV, GIME13 and GIXYC, for millet GIMNV and GCDM, for leek GIME13 and GIXYC. For P uptake, theses isolates are also the best though we noticed preference of some crops for some isolates or mixtures of two isolates. In order to select some effective isolates, a certain number of other criteria were assessed such as spore viability and germination, acidity tolerance, competitiveness under natural conditions and activity during storage and according to environmental factors (temperature: 4 and 25°C, storage duration: 1, 2 and 3 years).

An assessment was made under controlled conditions in order to have some significant data on inoculum production. The aim was to have enough inoculum of known quality (increased concentration of spores, assess the infectivity, high activity and viability of AMF). This was done using sterilised arable soil, on 10 litter pots using 2 plant/pot of millet (Pennisetum americanum) and 50 g/pot each of 5 isolates of AMF (Glomus clarum, Glomus hoi*, Gigaspora margarita, Glomus sp., Glomus intraradices, Scutellospora gregaria and S. heterogama), the experiment was replicated 10 times for each isolate.

Table 1. Response of mycorrhizal fungi inoculation on phosphorus uptake (mg/plant) and root colonization (%) on millet (*Pennisetum. americanum*), cowpea (*Vigna. unguiculata*) and leek (*Allium porum.)* under nursery conditions.

Strains	Cowpea [2]		Millet[1]		Leek[1]	
	P uptake	Root col.	P uptake	Root col.	P uptake	Root col.
GCHX	11.00	65[de]	35.67	71[f]	2.29	24[c]
GISM	19.00	72[f]	38.13	78[g]	1.65	15[ab]
GABC2	13.20	46[b]	24.33	58[d]	0.76	20[bc]
GCDM	15.50	53[c]	**116.8**	90[h]	1.36	19[bc]
GANM1	11.78	62[d]	37.42	52[c]	4.20	24[c]
GiMNV	**26.50**	89[g]	**237.74**	98[i]	**4.72**	32[d]
GiME13	14.67	85[g]	27.81	76[fg]	**14.10**	52[f]
GiXYC	13.80	85[g]	17.29	65[e]	2.35	48[e]
GVAM	18.70	58[bd]	21.75	32[b]	1.62	24[c]
GGNR	13.52	23[a]	30.46	19[a]	1.45	24[c]
GISM+GABC2	38.70	69[ef]	47.78	70[f]	0.69	12[a]
Non mycorrhizal control	3.70	0	6.80	0	0.51	0

LSD at 5% significance. [1]Harvest 90 days after planting, [2]60 Harvest days after planting (5 plants/ treatment)

In order to compare the effectiveness of different inoculants (*Glomus clarum*, *Gigaspora margarita* and Myco 4, a mixture of 6 Glomus and Gigaspora species) on the same crops, onion and shallot were used and some parameters assessed: root colonisation, P uptake, phosphatase activity and plant growth were analysed. On both crops, the inoculum made by *Glomus clarum* provided a good root colonisation and was considered as the best for plant improvement compared to the others. (Table 2).

Table 2: Response of onion (Stuttgartter giant variety)and shallot (*Allium cepa*) inoculation using three arbuscular mycorrhizal fungi under controlled conditions (12 weeks after planting), a) Onion, b) Shallot.

a) Onion (Stuttgartter giant variety)

Inocula	Root colonisation (%)	Biomass (g/plant)	Bulb weight (g/plant)	Acid Phosphatases activity (unit/plant root)
Control	0	7.2	3.2	1.85
Glomus clarum	80	15.5	4.3	4.94
Gigaspora margarita	60	7.8	3.3	2.40
Myco 4 mixture	20	5.1	2.1	1.49

b) Shallot (local variety)

Inocula	Root colonisation (%)	Biomass (g/plant)	Bulb weight (g/plant)	Acid Phosphatases activity (unit/plant root)
Control	0	18.1	10.9	4.29
Glomus clarum (M_1)	60	40.5	30.0	4.76
Gigaspora margarita	50	27.8	21.6	4.82
Myco 4 mixture	25	16.2	8.3	3.98

So as to understand the functioning of specific isolates during the course of symbiosis establishment using onion, an investigation was done using the 5 isolates of AM fungi (*Glomus clarum, Glomus hoi*, Gigaspora margarita, Glomus* sp., *Glomus intraradices*). Parameters assessed were: spore concentration, inoculum infectivity, root colonisation, root growth and surface occupation, P uptake, acid phosphatase activity and plant growth were analysed. The effect of AM fungi ranged from 34% to 126 % root surface occupation increase, 17% to 86 % increase for acid phosphatases activity and after 90 days from 0 to 88 % increase for onion biomass. Some isolates are better than others. A positive and significant correlation was obtained between root surface occupation and root colonisation by AMF (+ 76 %), root length (+ 93 %), acid phosphatases activity (+ 94 %), P uptake (+79 %), N uptake (+ 76 %) and onion biomass (+ 91 %).

Legume-rhizobia symbiosis and mineral nutrition

Preliminary studies were done on the characterisation of some species of Crotalaria and their symbiosis with rhizobia and mycorrhizal fungi from Ngaoundéré zone. Results indicated a rich diversity of native specimens and a high dependency of some species of cover crop legumes on rhizobia and mycorrhiza for their development. A preliminary evaluation of the effect of molybdenum application and rhizobia inoculation was done using groundnut in two contrasting sites (Bokito and Yaoundé). For most parameters tested (nodulation, plant biomass, yield and nitrogen uptake) were significantly very high in Yaounde site compared to Bokito site. Molybdenum application or rhizobia inoculation was effective when the number of native rhizobia were low in Yaoundé site (100 cells/g) compared to Bokito one (10.000 cells/g). Results show the potential of molybdenum and rhizobia to increase the grain/pod ratio from 52 % to 73 % only in Yaoundé site, while in Bokito site this ration was high for the control and the treatments (74-75).

Combining Legumes-rhizobia-AM fungi

Most field experiments in Cameroon indicated that when legumes are combined with rhizobia and mycorrhizal fungi, a synergistic effect was noticed. An excellent example is the growing of cowpea in a poor ferralitic soil where results showed that the double rhizobial and mycorrhizal inoculation (R+M+) increases flowering precocity of cowpea by 6 days compared to the non-inoculated control (R-M-). Increase of biomass yield from inoculation was about 4, 5 and 6 times higher for R+M-, R-M+ and R+M+ treatments respectively compared to the control (R-M-). Beside, R+M+ treatment gave the best pod yield (3.58 $t.ha^{-1}$), followed by R-M+ treatment (3.28 $t.ha^{-1}$), R+M- treatment (1.51 $kg.ha^{-1}$) and the R-M- control (0.25 $t.ha^{-1}$). Inoculating cowpea with rhizobia (“Cynthia T.”), mycorrhiza (“Myco 3”) and the mixture of the two increased the cowpea pod yield by 6.6, 14.3 and 15.6 respectively compared to the non-inoculated control.

Soil fertility management may also change AM Fungi activity, for example Stylosanthes mulch incorporation, manure, rhizobia and molybdenum application may increase spore number and mycorrhiza root colonisation of maize on farm.

In summary, a microbial resource bank of beneficial organisms was initiated (this include AM fungi, rhizobia and P-solubilising micro-organisms). AM fungi studies have provided knowledge on the activities and limitations on these soil organisms. Most results clearly indicated that increasing the activities of AMF may significantly improve crop yields in acidic soils conditions of Cameroon. The laboratory is regularly producing AM fungi for more than 6 years at pilot scale, this bio-fertiliser may be stored for 3 years maintaining its activities. Prepared manuscripts out of these results will be submitted in refereed journals for publication. The collection of plant beneficial micro-organisms under development is certainly the most important genetic resources in Cameroon. Many post-graduate and PhD students have been trained on this eco-friendly approach, but still, there is a huge need to involve more farmers’ organisations in this work.

Site 2: Niger

Biological nitrogen fixation in Banizoumbou and Gaya, Niger

15N dilution technique was used to quantify the biological nitrogen fixation of three cowpea varieties (local, TN5-78 and Dan illa) under different soil fertility conditions (Photo 1). A non-fixing (NF) cowpea variety was used as non-fixing crop. The samples have been sent to JIRCAS laboratory in Japan for mass spectrophotometer analysis of 15N in order to assess the biological nitrogen fixation.

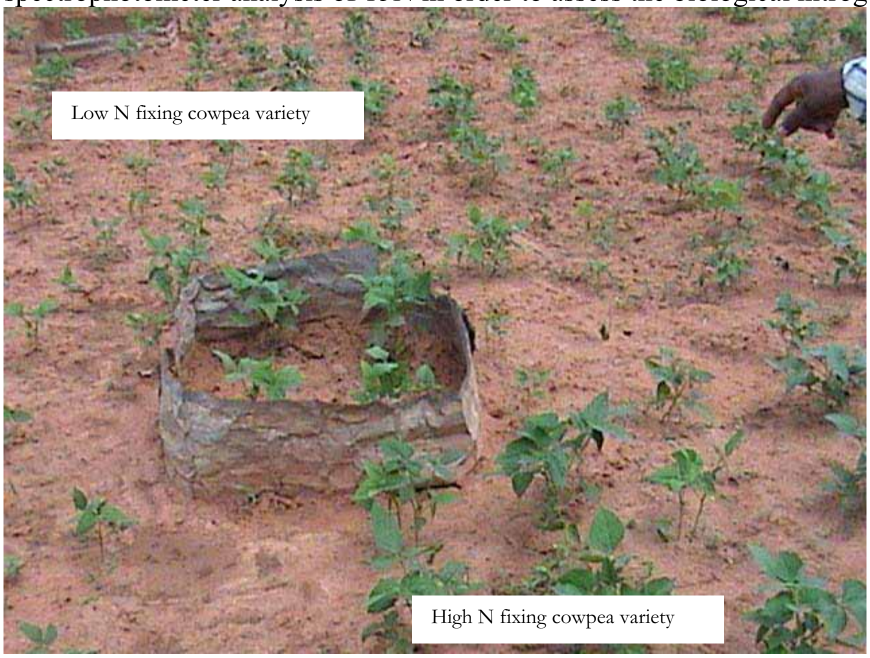

Photo 1: Cowpea varieties in N fixation trial at Gaya, Niger. Different cowpea varieties have different capability in N fixation.

Interaction between Water management and nutrient management in African Dry Lands

Water harvesting techniques such as the tide ridges and the Zai system combined with the use of plant nutrient could be an excellent approach for a win-win situation where the nutrient use efficiency will be increased with the capture of water and also the water use efficiency will increase with the improvement of soil fertility. This win-win situation will result in higher and sTable crop production within the African desert margins.

Activities were implementation very successfully in Niger, Mali, Kenya and Burkina Faso. This was done by AfNet scientists who had received training on additional methodologies for effective intervention. The field activities were implemented in Niger, Mali, Kenya and Burkina Faso using appropriate water harvesting techniques and therefore facilitated comparisons across the desert margins of the African continent. The results to be highlighted in this report will be from three sites (Niger, Kenya and Mali) where this experiment had been implemented by the end of 2003 but results from Burkina Faso site where the trial was implemented in 2004 will be available at the end of this cropping season. Plans are underway to initiate the same field trial in Senegal.

Site 1: Niger

Combining water harvesting techniques and integrated nutrient management for sustainable food production in the Sahel

Due to the increased population pressure and the limited availability of fertile land, farmers in the desert margins increasingly rely on marginal or even degraded land for agricultural production. The farmers rehabilitate these lands with different technologies for soils and water conservation. Among these is the zai (Photo 2), an indigenous technology for land rehabilitation, which combines water harvesting by means of small pits and hill-placed application of organic amendments.

Photo 2: The Zai system in the Sahel.

To study the resource use efficiency of this technique in the context of the Sahel of Niger, an experiment was conducted at two locations on degraded bare lands in a farmer field from 1999 to 2000. In these experiments, the effect of organic amendment type (millet straw and cattle manure (3 t ha^{-1}) and water harvesting (with and without water harvesting pit) on millet grain yield, dry matter production and water use were compared.

Results showed a high effect of Zai technique on yields response and plant establishment.

Plant establishment: statistical analyses showed a high effect zai on plant establishment and it's effect on organic fertilizer applied. Average number of successful hills was 4957 per ha for the zai plots significantly different from no zai plots with 1310 hills per ha (p=0.000). There was also an effect of organic matter application (manure) on number of hills per ha whether or not water-harvesting techniques (zai) were applied (Table 3).

Table 3: means comparison for millet hills number per ha (Duncan test)

Treatments	Mean number of hills per ha
No zai + no manure	1310a
No zai + with manure	3331b
Zai + no manure	4957c
Zai + with manure	7572d

P=0.000

Table 4 below shows the effect of the zai system on millet and cowpea yields. It was observed that in an intercrop, pearl millet yields were about 273 kg/ha in zai compared to only 87 kg/ha from the plots with no zai system. There was no significant difference for the cowpea yields.

Table 4: Pearl millet and cowpea yields as influenced by water harvesting method

Treatments	Millet yields (kg/ha)	Cowpea yields (kg/ha)
Zai	273	16
No zai	87	17
Manure	267	19.6
No manure	92	14.0
Pure millet	183	16.7
Millet/Cowpea intercrop	176	
Interactions		
Organic matter/cropping systems		
Manure-millet/cowpea	265	19.6
No manure-millet/cowpea	87	14.0
Organic matter/cropping system/water conservation		
Zai x Manure x Intercrop	438	16.7
Zai x No manure x Intercrop	104.5	15.7
No Zai x Manure x Intercrop	92	22.6
No Zai x No manure x Intercrop	69	12

The use of the Zai system in the Sahel has proved to be a good technology for Pearl millet production.

Site 2: Mali

This experiment was setup in Mali in 2003 at Siribougou, a rural village located at about 35 km west of Ségou. The main research hypothesis this project aims to test is that combining water-harvesting techniques (Photo 3) with the effective nutrient management will result in higher efficiency of resources and will increase the profitability of the investment in water harvesting. The experimental design allows to compare the combined effects of water and nutrient management on three cropping systems, namely i) continuous cereal, ii) cereal-legume rotation and iii) cereal and legume intercropped (Table 5). One year of data collection has just been completed.

Photo 3: Water harvesting through the use of ridge tillage along contour lines in Siribougou, Mali, 2003.

Table 5: Treatment structure at Siribougou, Mali.

Treatment no.	Description
1	Cereal + P + N
2	Cereal + P – N
3	Cereal - P – N
4	Cereal + P + N0
5	Cereal + P + N1
6	Cereal + P+ N2
7	Cereal + P+ N3
8	Cereal + Leg +P + N
9	Cereal + Leg + P – N
10	Legume + P + N
11	Legume + P – N
12	Legume - P – N

Due to the excessive rains received in this site, there was no significant effect noted due to water harvesting. Nonetheless, the integration of water harvesting and mineral fertilizer and manure application proved superior in increasing millet grain yields in Mali (Figure 4). There was an increase of about 200 kg/ha of pearl millet grain yields with application of water harvesting technology. This was only noted in the treatment whereby mineral N was applied.

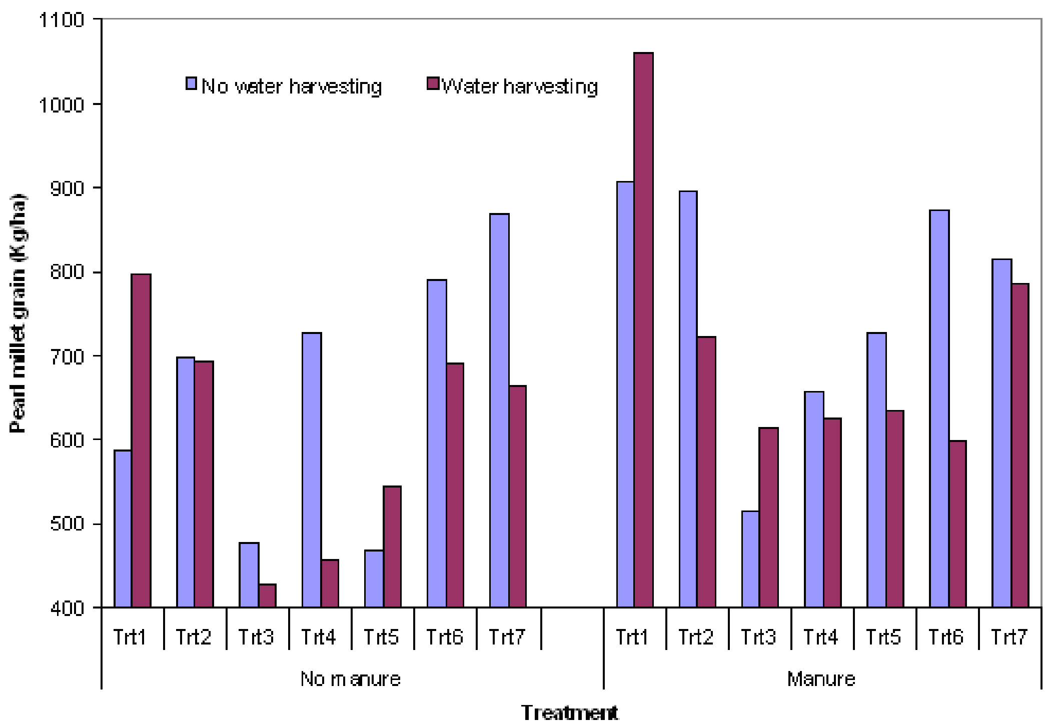

Figure 4: Pearl millet grain production as influenced by water harvesting, manure and mineral fertilizer application at SIRIBOUGOU, Mali in 2003.

The control treatment gave the lowest pearl millet grain yield (about 400 kg/ha). In plots which had no manure, there was response to N application regardless of whether there was water harvesting or not. With water harvesting and manure application, there was no N response noted. However, millet yield response to N was observed in plots without water harvesting.

Pearl millet grain yield obtained from an intercrop with beans was about 800 kg/ha with water harvesting while yield without water harvesting was about 600 kg/ha (Figure 5). This was only true with manure and mineral fertilizer application.

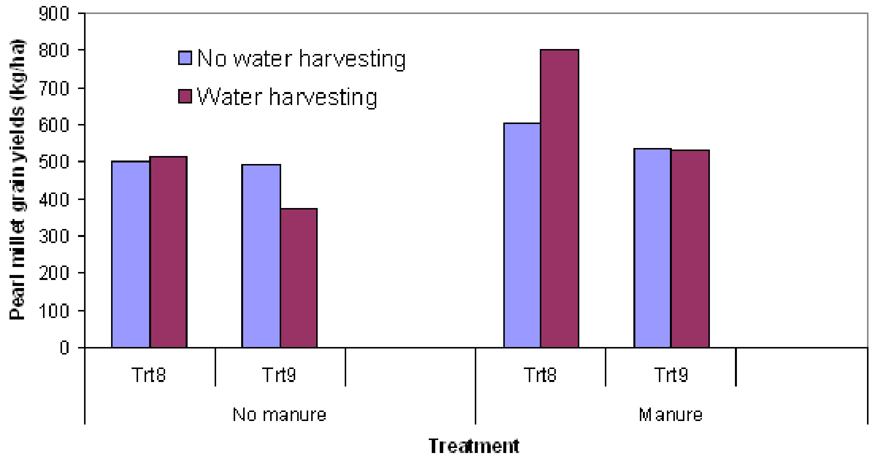

Figure 5: Pearl millet grain production in an intercrop with common beans as influenced by water harvesting, manure and mineral fertilizer applications at SIRIBOUGOU, Mali in 2003.

Bean grain yield in an intercrop with pearl millet was also influenced by water harvesting (Figure 6). In the absence of mineral nitrogen, the yield from plots where water harvesting was about 1043 kg/ha while only 709 kg/ha was obtained from plots where no water harvesting was practiced. This was only true with the manure plots. There was no significant difference observed between water harvesting and no water harvesting in plots which did not receive manure.

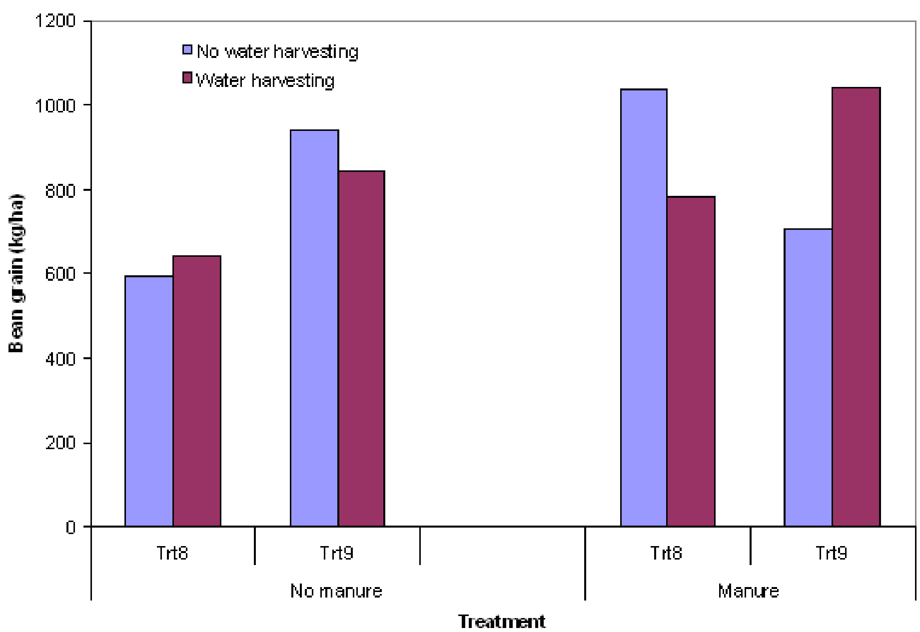

Figure 6: Bean grain production in an intercrop with pearl millet as influenced by water harvesting, manure and mineral fertilizer applications at SIRIBOUGOU, Mali in 2003.

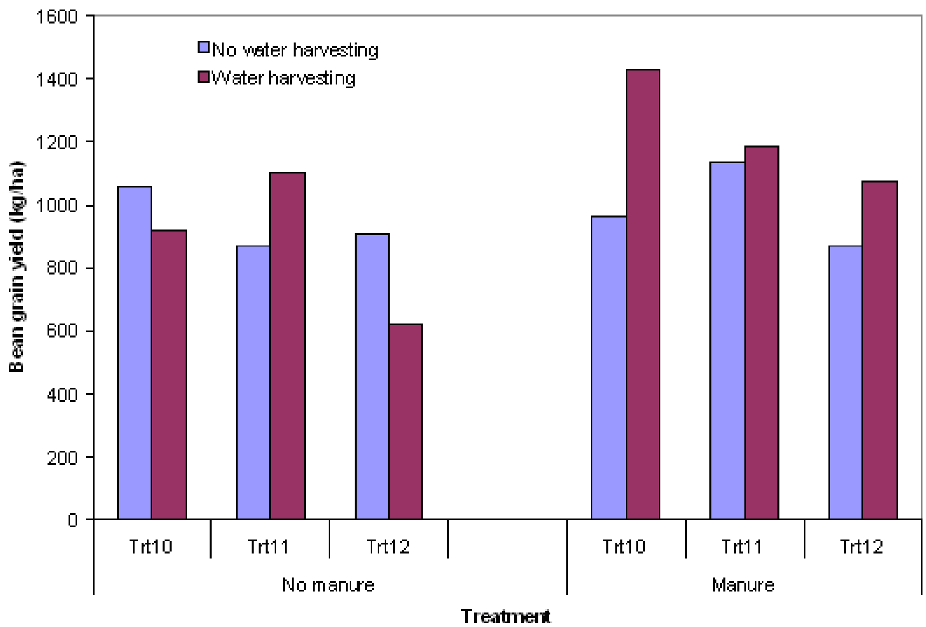

Figure 7: Bean grain production as influenced by water harvesting, manure and mineral fertilizer applications at SIRIBOUGOU, Mali in 2003.

The application of manure coupled with water harvesting and mineral fertilizer application gave the highest bean grain yield (Figure 7). This was about 1428 kg/ha compared to 962 kg/ha obtained from plots which received manure and mineral fertilizer but no water harvesting.

Although water harvesting technologies improved on the grain yields of both pearl millet and beans, it could be noted from these preliminary results that the inclusion of external inputs was ineviTable in this region.

Site 3: Kenya

This study was started in the semi-arid areas of Makueni district in eastern Kenya during the long rains (LR) of 2003. The semi-arid area in Makueni district is in agro-ecologicqal zones (AEZ) 5 (Jaetzold and Schmidt, 1983). Rainfall is bi-modal and, as is typical of semi-arid areas, it is low and erratic. The short rains (October to January) are generally have more rainfall and are more reliable than the long rains (March to June). Temperatures are high giving rise to high evapo-transpiration.

Experimental design and treatments

A split-split-split plot experimental design was used with water harvesting vs conventional tillage as the main treatments; and manure vs no manure application as the sub-plots. The sub-plots were split into three crop management systems i.e. (1) Legume-cereal rotation, (2) legume-cereal intercrop and (3) continuous cereal. In each crop management system different fertilizer treatments was applied as indicated below;

Tied-ridges was used as the water harvesting method. Ridges (30 cm high) and ties (cross ridges, 20 cm high) was constructed using a oxen driven ridger to create a series of basins for storing water. The spacing of the ridges was 90 cm and the cross ridges were at 2.5m interval.

Goat manure at a rate of 5tha^{-1} was applied in the planting holes. Fertilizer was applied at 0 and 40 kg P ha^{-1} in treatments having P; and 0, 40, 80 and 120 kg N ha^{-1} for plots receiving nitrogen. Tripple superphosphate (TSP) and Calcium ammonium nitrates (CAN) fertilizers were used as source of P and N respectively. Each treatment was replicated four times in a completely randomized block design.

The individual plot size ws 5 m long and 5 m wide. Maize (Katumani composite B) and cowpea (K80) was planted on 9-10th April 2003 at 90 x 30 cm spacing in pure stands. Maize and cowpea was intercropped in the same row but alternating planting holes.

Topsoil samples were taken at the start of the experiment from 0-30 cm depth at the main plot level for organic C, total N, available P, pH and texture determination. Weeding was done twice in the season. Thinning was done 10-11th June 2003 (60 days after planting) to a single plant per hill. During the thinning, three cowpea and two thinned maize plants were sampled for dry biomass determination. Harvesting was done on 12-15th August 2003 (from a 3x1.8 m^2 area at the middle of the plot) and plant samples taken for dry matter and yield determination.

From the general observation during germination period, it was noted that germination in tied-ridges appeared better than in plots where there were no tied ridges (Photo 4).

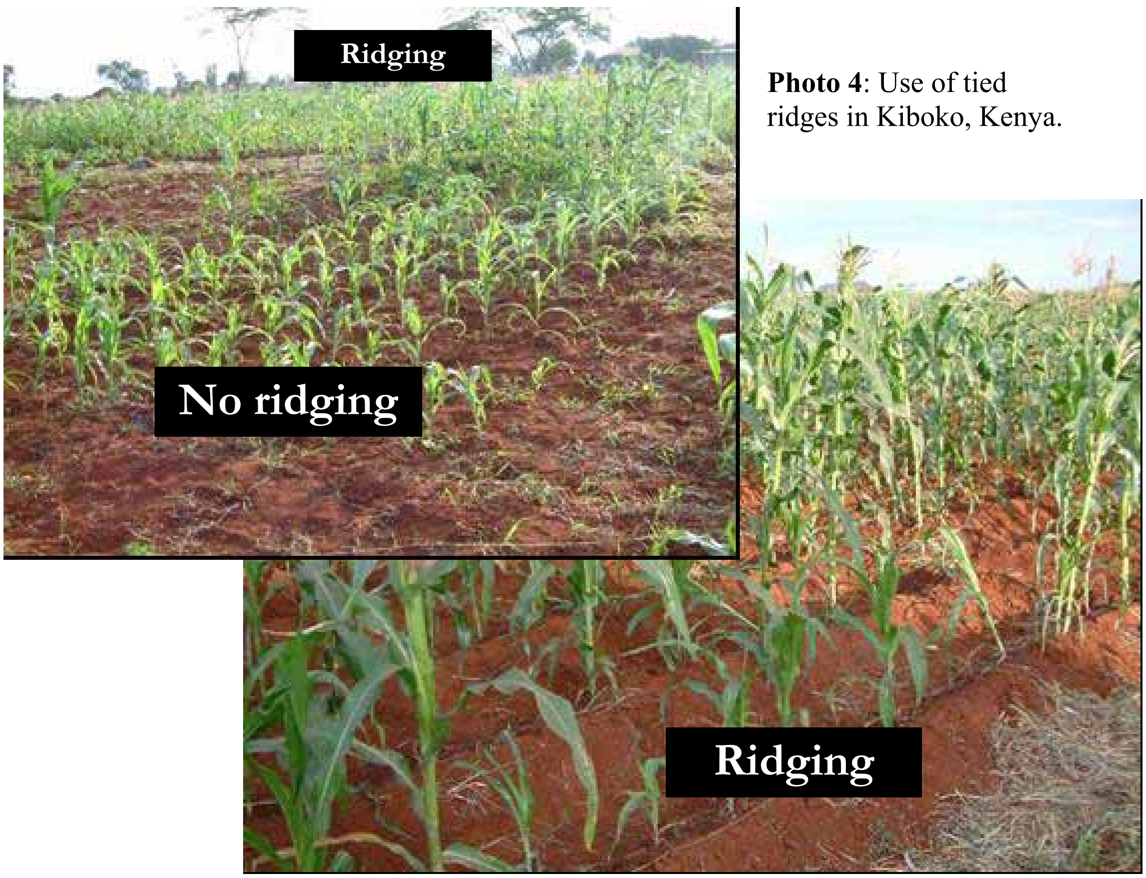

Photo 4: Use of tied ridges in Kiboko, Kenya.

Unlike in Mali where pearl millet responded to water harvesting and mineral fertilizer application, there was no significant effect of water harvesting on maize grain yield in the Kenyan site (Figure 8). The average maize grain yield obtained with water harvesting was about 1.7 – 2.7 t/ha while in plots where there was no water harvesting the yiled ranged between 1.6 – 2.9 t/ha. This could be attributed to the relatively high rainfall received during the study period. The application of manure did not have any marked effect on maize grain yields in this site too. For plots which received manure, application of mineral N fertilizer beyond 80 kg N/ha seemed to reduce maize grain yield.

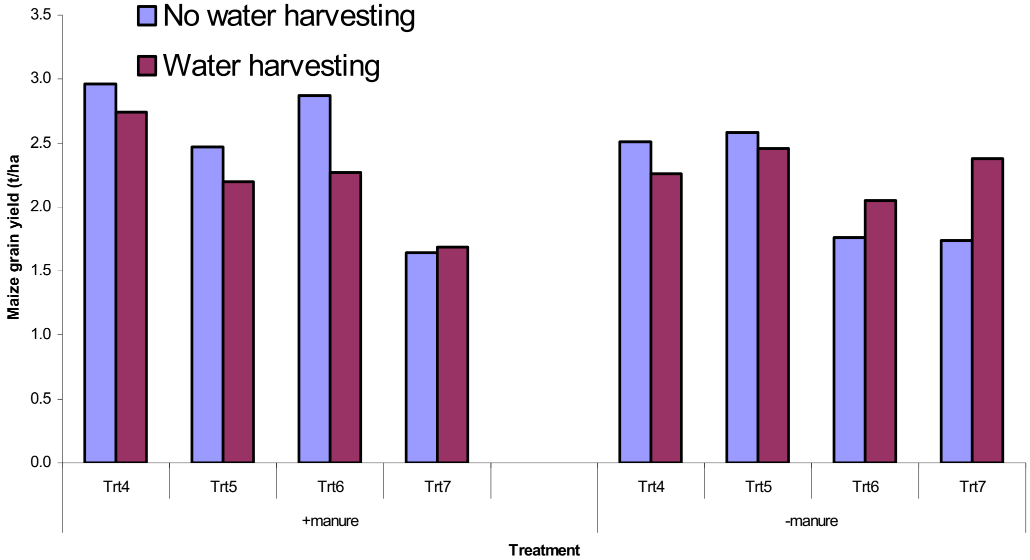

Figure 8. Effect of water harvesting, manure and mineral fertilizer application on maize grain yield at Kiboko, Kenya 2003 rainy season.

Site 4: Burkina Faso
Activities in this site were initiated in 2004 and the data is not yet analyzed. This will be available at the end of this cropping season.

In summary, it was noted that in Niger, the proposed methodologies and approaches in soil fertility management are well appreciated by both farmers and NARES scientists in the Sahel. The use of the zai technology was a success story in this particular site. This technology is combined with the use of plant nutrient to create a win-win situation where the nutrient use efficiency will be increased with the capture of water and also the water use efficiency will increase with the improvement of soil fertility. This win-win situation will result in higher and sTable crop production. In Mali the use of ridge tillage along contour lines proved to be superior to farmer practice and this technology will be tested further in on-farm trials. Although the use of tied ridges was noted to be the best technology for the drier areas in Kenya, this was not quite conclusive because the trial was affected by unevenly distributed rains received during the growing period. These results will be validated through the second year data. Activities in Burkina Faso were begun in 2004 and analysis is yet to be concluded. These results will be available at the end of this cropping season.

TSBFI-Latin America

Published Work

The impact of soil organisms on soil functioning under neotropical pastures: a case study of a tropical anecic earthworm species

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Agriculture Ecosystems & Environment 103: 329-342 (2004)
Martiodrilus n. sp. (Oligochaeta, Glossoscolecidae) is a large native earthworm from the natural savannas of the Eastern Plains of Colombia. The description of the main biological, ecological and functional

attributes of this species in a natural savanna and several introduced pastures at the Carimagua Research Station (320 km east from Villavicencio) was the main objective in this study. Density and biomass of this species were significantly much higher in the introduced pastures compared with the savanna (ANNOVA, P<0.01). Evidence of vertical migration during the year was observed, while it is active in the topsoil during the beginning of the rainy season, it enters in a true diapause to withstand adverse environmental conditions before the onset of the dry period, being adults the last to enter into this phase (after reproduction period). *Martiodrilus* n. sp. seemed to select food substrates with high organic contents since casts produced in the two systems had significantly higher total C and total N contents than the bulk soil. Besides, C content also increased significantly during ageing of casts (+100%), possibly because of CO_2 fixation processes, accumulation of dead roots and/or macrofaunal activities. The effects of earthworm activities on soil and cast seed banks were revealed in another experiment. The composition of the above standing vegetation was relatively closer to that of the cast seed bank than that of the soil seed bank. The results obtained in this study support the general knowledge of how earthworms can affect soil fertility and plant growth. *Martiodrilus* n. sp., through the production of casts affects the availability and nature of both the spatial and trophic resource in soil. This species certainly belongs to the functional group of "ecosystem engineers", as it affects the availability of some resources for other organisms through the production of physical biostructures. The next step in research should be directed now to test whether *Martiodrilus* n. sp. is a keystone species within the soil community or not.

Soil macrofaunal communities in permanent pastures derived from tropical forest or savanna
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Agriculture Ecosystems & Environment 103: 391-312 (2004)
Soil macrofauna are sensitive to land use changes and this may have implications to soil functioning. The impact of the conversion of native ecosystems into extensive or intensive pastures on soil macrofauna were assessed with a standardized methodology in two neotropical phytogeographical regions, i.e. a tropical savanna area (Eastern Plains of Colombia) and a tropical rain forest area (Brazilian Amazon). In the savanna area, extensive cattle ranching only led to a slight enhancement of earthworm populations and to short-term fire-induced decreases of macrofaunal density. In intensive pastures, the initial taxonomic richness and composition of soil macrofauna were maintained, while native earthworm biomass was strongly increased. This may be explained by the similar mesologic conditions between these systems (similar vegetation structure) and by the higher quality of the organic inputs in the pastures (roots, litter and cattle faeces). Increased macrofaunal activity with a high taxonomic diversity is expected to have positive impacts on the sustainability of pastures in Colombian savannas. In the Amazon basin, slashing and burning of the forest for intensive pasture establishment resulted in more dramatic effects on native macrofauna. Taxonomic diversity was particularly strongly affected. Native earthworm species were largely depleted at the expanse of exotic peregrine species like, e.g. *Pontoscolex corethrurus.* These results are probably bound to the deep environmental changes that follow the conversion of forest into grassland ecosystems. Such modifications of macrofaunal communities are known to have potential negative effects on soil functioning and on the sustainability of agropastoral systems in this area.

Condiciones hidrofísicas de suelos con alta saturación de magnesio en el Valle del Cauca, Colombia (Hydrophysical conditions of soils with high magnesium saturation in the Cauca Valley of Colombia)

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In Cauca Valley of Colombia, there are 116,872 hectares of soils in which the dominant ion in the cation exchange capacity (>20 cmol(+) kg^{-1}) is Mg^{+2} (>40%). The soils are Vertisols. High Mg^{++} saturation may causes marked negative effects in the soil properties that are related to plant responses and crop production. The purpose of this study was to evaluate and characterize soil physical conditions in magnesic soils. It was found that the soils (dominated by vemiculites and esmectites) presented the following general physical characteristics: clay content higher than 55%, plasticity index higher than 45%, COEL index higher than 0.10%, very high bulk density (>1.7 $Mg.m^{-3}$), and very low total porosity (<30%). They presented massive soil structure or it was very weak. From the point of view of water flow they showed great constraints. Basic infiltration varied from 1.19 to 0.34 $cm.h^{-1}$, saturated hydraulic conductivity from 0.18 to 0.44 $cm.h^{-1}$, sorptivity from 0.025-0.084 $cm.S^{-0.05}$, water pressure for air entry varied from 4.7 to 27.7 cm. The non-saturated hydraulic conductivity can be represented by an equation of the following form: $ae^{0.05h}$, were h=matric potential and a is a soil coefficient. From this characterization it is concluded that these soils, have constraints for crop production and must be managed to increase total porosity and macroporosity. If this is achieved it is possible to improve soil water infiltration, soil drainage and soil aeration, therefore, developing a better environment for root growth, which in turn will improve the general soil condition and its productivity.

Volumetric changes in magnesic soils as they dry in the Cauca River Valley, Colombia

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An extensive area of loamy soils has been recognized in the Cauca River Valley to have high magnesium saturation values. They are called "Magnesic Soils". These soils are of special interest because they are being used for intensive agricultural production. They require previous knowledge of their behaviour to define the soil management practices that have to be used in order to avoid degradation and to increase productivity. The purpose of this study was to evaluate the physical characteristics of these soils in relation to changes in soil volume as they are getting drier. Thirteen soils profiles were selected, described and sampled for the study. The changes in soil volume of core samples taken in cylinders of known volume, were determined under laboratory controlled conditions as soil dried. The following contraction indices were determined: specific volume (ν), specific volume full of air (P), moisture content (θ), normal shrinkage (n) and residual shrinkage (r). Soil shrinkage varied from 0.44 m^3 Mg^{-1} to 0.27 m^3 Mg^{-1}, depending on the topographic position, with higher values at the flat position. In general, it was found that there was a volume reduction of around 28% as the soil dried from saturation to a suction of 1500 MPa. These volume changes were directly associated to clay content (r=0.53) and initial bulk density (r=0.52). Volume changes were higher at low water suctions. The slope of the normal shrinkage varied from 1.33 to 0.63 and that of the residual shrinkage from –0.83 to –0.50, depending on Mg^{++} content. There was a strong association between Mg^{++} and the presence of esmectites and vemiculites. The change in soil volume as it dries, should be taken into account for developing soil management practices.

Root Distribution and Nutrient Uptake in Crop-forage Systems on Andean Hillsides

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Root growth and distribution of crop and forage components of production systems on hillsides could have important effects on nutrient acquisition and plant growth as well as on soil loss. A long-term field experiment was established in 1994 in the Andean hillsides region of Cauca, Colombia. Soils at the site are medium to fine textured Oxic Dystropepts derived from volcanic-ash deposits. Four treatments, cassava monocrop, cassava + cover legumes intercrop, elephant grass pasture, and imperial grass pasture, were selected to determine differences in dry matter partitioning, leaf area index, nutrient composition, root distribution (0-80 cm soil depth), nutrient acquisition and soil loss. Root biomass of the cassava + cover legumes intercrop was 44% greater than that of the cassava monocrop. The presence of cover legumes not only reduced soil erosion but also improved potassium acquisition by cassava. Among the two pastures, elephant grass pasture had greater root biomass (9.3 t/ha) than the imperial grass (4.2 t/ha). The greater root length density (per unit soil volume) of the former contributed to superior acquisition of nitrogen, phosphorus, potassium and calcium from soil. In addition, the abundance of very fine roots in elephant grass pastures in the topsoil layers reduced the loss of soil from the steep slopes. These results indicate that (i) the presence of cover legumes can improve potassium acquisition by cassava; and (ii) elephant grass can be used as an effective grass barrier to reduce soil erosion in Andean hillsides.

Soil phosphorus dynamics, acquisition and cycling in crop-pasture-fallow systems in low fertility tropical soils of Latin America

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Knowledge of the P dynamics in the soil/plant system and especially of the short- and long-term fate of P fertilizer in relation to different management practices is essential for the sustainable management of tropical agroecosystems. Since 1993, CIAT researchers in collaboration with NARS partners have conducted long-term field studies on soil P dynamics, acquisition and cycling in crop-pasture-fallow systems of low fertility tropical soils of the savannas and hillsides agroecosystems of Latin America. The progress made from these long-term studies that were partially supported by special project funds from ACIAR (LWR2/1999/03) is described in this article. In tropical savannas in the Llanos of Colombia, soil P dynamics, acquisition and cycling were quantified in cereal-legume rotations (Maize-soybean or rice-cowpea) and ley pasture systems. Measurements of soil P fractions indicated that applied P moves preferentially into labile inorganic P pools, and then only slowly via biomass production and microbes into organic P pools under both introduced pastures and crop rotations. Field studies conducted to quantify the residual effectiveness of P fertilizer inputs in crop rotations in terms of both crop growth response and labile P pool sizes indicated that soluble P applications to oxisols of Colombia remain available for periods of time which are much longer than expected for "high P-fixing"soils, such as the oxisols of Brazilian Cerrados. In Andean hillsides of Colombia, the impact of short-term planted fallows to restore soil fertility in N and P deficient soils by enhancing nutrient recycling through the provision of soil organic matter (SOM) was investigated. Results indicated that the fractionation of SOM and soil P could be more effective for detecting the impact of planted fallows on improving soil fertility than the

conventional soil analysis methods. Litterbag field studies contributed to characterization of the rate of decomposition and nutrient release from twelve different plant materials that could serve as biofertilizers. The data sets from these long-term experiments from the tropical savannas and hillsides agroecosystems of Latin America could be valuable for further testing and validation of APSIM model.

Carbon and nutrient accumulation in secondary forests regenerating from degraded pastures in central Amazônia, Brazil

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Over the past three decades, large expanses of forest in the Amazon Basin were converted to pasture, many of which later degraded to woody fallows and were abandoned. While the majority of tropical secondary forest (SF) studies have examined post-deforestation or post-agricultural succession, we examined post-pasture forest recovery in ten forests ranging in age from 0 to 14 yrs since abandonment. We measured aboveground biomass and soil nutrients to 45 cm depth, and computed total site C and nutrient stocks to gain an understanding of the dynamics of nutrient and C buildup in regenerating SF in central Amazônia. Aboveground biomass accrual was rapid, 11.0 Mg ha^{-1} yr^{-1}, in these young SF. After 12 to 14 yrs, they accumulated up to 128.1 Mg/ha of dry aboveground biomass, equivalent to 25 to 50% of primary forest biomass in the region. Wood N and P concentrations decreased with forest age. Aboveground P and Ca stocks accumulated at a rate of 2.4 and 42.9 kg ha^{-1} yr^{-1}; extracTable soil P stocks declined as forest age increased. Although soil stocks of exchangeable Ca (207.0 ± 23.7 kg/ha) and extracTable P (8.3 ± 1.5 kg/ha) were low in the first 45 cm, both were rapidly translocated from soil to plant pools. Soil N stocks increased with forest age (117.8 kg ha^{-1} yr^{-1}), probably due to N fixation, atmospheric deposition, and/or subsoil mining. Total soil C storage to 45 cm depth ranged between 42 and 84 Mg/ha, with the first 15 cm storing 40 to 45% of the total. Total C accrual (7.04 Mg C ha^{-1} yr^{-1}) in both aboveground and soil pools was similar or higher than values reported in other studies. Tropical SF regrowing on lightly to moderately-used pasture rapidly sequester C and rebuild total nutrient capital following pasture abandonment. Translocation of some nutrients from deep soil (>45 cm depth) may be important to sustaining productivity and continuing biomass accumulation in these forests. The soil pool represents the greatest potential for long-term C gains; however, soil nutrient deficits may limit future productivity.

Completed Work

Effects of sample post harvest treatment on aerobic decomposition and anaerobic *in-vitro* digestion of tropical legumes with contrasting quality

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The aerobic decomposition of plant materials is a slow process and thus methods used to estimate degradation rates on the soil are time and resource consuming. Earlier studies have shown highly significant correlations between *in-vitro* dry matter digestibility (IVDMD) and plant decomposition under field conditions. The authors suggested the usefulness of applying time saving methods used to assess forage quality for ruminants to predict decomposition of plant material on the soil. Such a rapid

laboratory "test" could be useful for screening germplasm with potential contribution to soil improvement, to reduce costs and contribute to higher research efficiency.

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) were used either fresh, freeze-dried, frozen, oven-dried (60 ^{o}C) 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 (Table 6).

Table 6. Effect of post harvest treatments on initial chemical characteristics of the three legume species. Values are in % of mean dry weights.

Plant	Post harvest	C	N	ND	sd	AD	sd	IAD	sd	sC	sd	bC	sd	PP	sd	ligni	Sd
Indigofera constricta	freeze-dried	42.	4.6	26.8	0.1	19.5	0.9	1.9	0.3	0	-	0	-	5.5	0.3	5.0	0.5
	oven-dried	41.	5.0	42.2	0.8	23.4	0.4	3.4	0.3	0	-	0	-	5.1	1.4	5.4	0.0
	air-dried	40.	5.3	29.9	2.5	23.0	1.9	3.2	0.2	0	-	0	-	5.0	0.9	4.5	0.2
Cratylia argentea	freeze-dried	41.	3.7	56.6	0.7	31.8	0.3	7.7	0.1	0	-	1.9	0.1	3.0	1.0	11.4	0.1
	oven-dried	41.	3.8	77.4	3.0	36.3	0.9	7.5	0.2	0	-	1.6	0.4	0.6	0.7	13.4	0.1
	air-dried	39.	3.9	66.7	2.0	32.9	0.4	7.0	0.7	0	-	2.0	0.3	2.8	0.3	12.6	0.1
Calliandra sp.	freeze-dried	43.	2.0	36.0	0.4	26.4	0.3	7.4	0.0	25.	1.5	5.0	1.7	43.	1.0	10.4	0.0
	oven-dried	43.	2.7	42.7	1.0	31.8	4.3	10.0	0.5	20.	4.6	5.0	1.4	27.	4.5	13.3	0.0
	air-dried	44.	2.3	34.8	0.6	32.2	4.0	7.8	0.6	23.	1.7	5.3	1.0	39.	1.6	8.5	0.3

CC=carbon, N=nitrogen, NDF=neutral detergent fibre, ADF=acid detergent fibre, IADF=indigestible acid detergent fibre, sCT=soluble condensed tannins, bCT bound condensed tannins, PP= polyphenols, sd=standard deviation, n= 2, except CT where n=3 and C/N where n=1

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 (Figure 9).

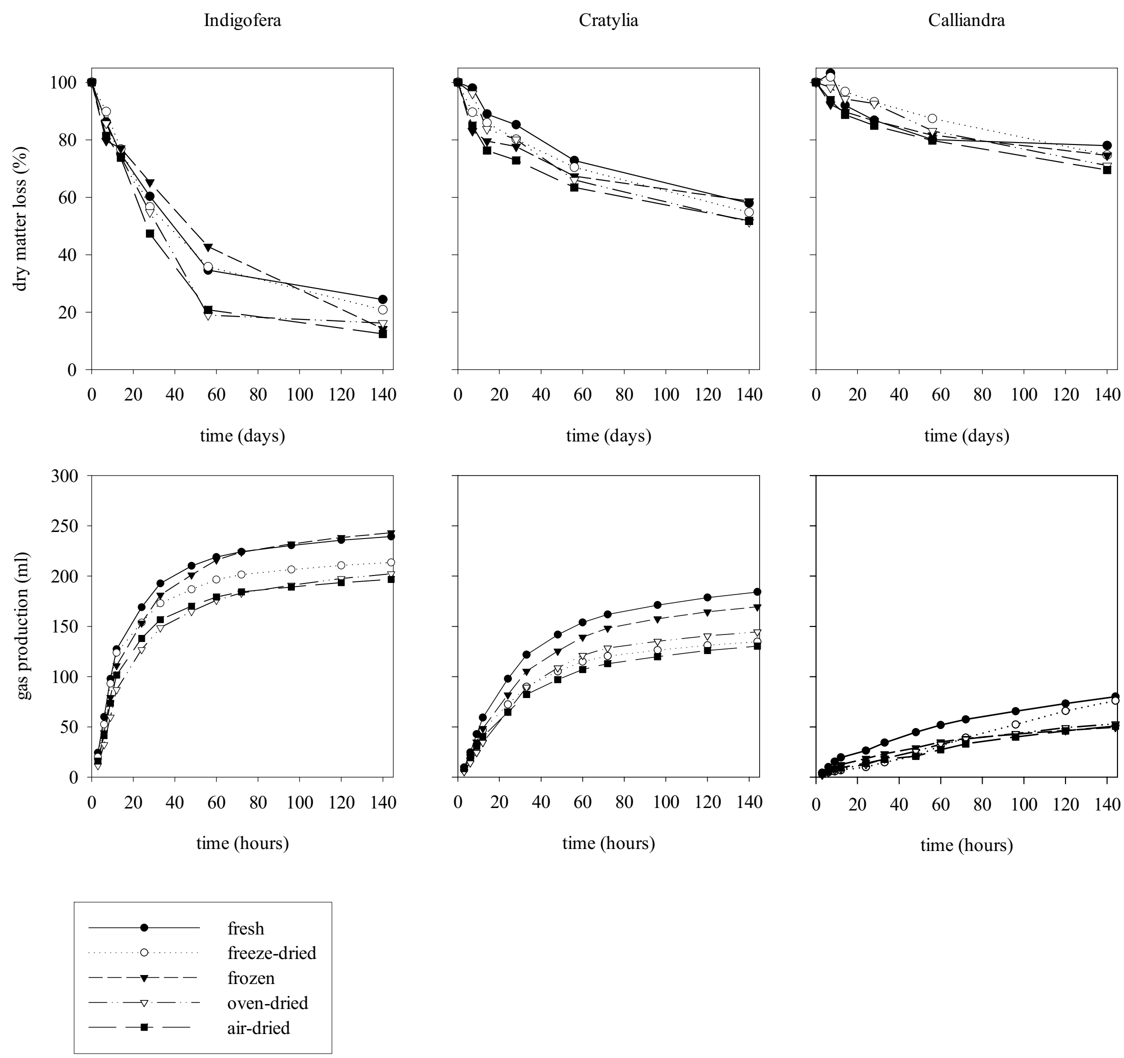

Figure 9. a) Percentage of initial dry weight remaining of Indigofera, Cratylia and Calliandra residues as affected by 5 different post harvest treatments during 140 days (aerobic methods) of decomposition in a greenhouse litterbag experiment, b) extent of gas production (ml) of Indigofera, Cratylia and Calliandra residues as affected by 5 different post harvest treatments during 144 h (anaerobic method) of incubation in a gas production experiment

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 to IVDMD ($r>0.80$, $p<0.001$) and gas production ($r=0.53$, $p<0.001$) (Table 7).

Table 7. Pearson correlation coefficients (r) between initial plant tissue quality and extent and rate of decomposition and gas production.

Plant tissue quality	Decomposition[1]		Gas production[1]	
	Extent	Rate	Extent	Rate
NDF	-0.22 ns (17)	-0.36 ns (18)	-0.08 ns (18)	-0.21 ns (18)
Ligning	-0.75*** (17)	-0.80*** (18)	-0.63** (18)	-0.66** (18)
Ligning+Bct	-0.94*** (17)	-0.91*** (18)	-0.87*** (18)	-0.86*** (18)
IADF	-0.90*** (17)	-0.86*** (18)	-0.88*** (18)	-0.87*** (18)
(ligning+PP)/N	-0.85* (9)	-0.73 ns (9)	-0.85** (8)	-0.82** (9)
CT	-0.80*** (24)	-0.64** (26)	-0.86*** (26)	-0.57** (26)
Ligning+CT/N	-0.85*** (17)	-0.73*** (18)	-0.91*** (18)	-0.88*** (18)
IVDMD	+0.89*** (57)	+0.80*** (59)	+0.89*** (59)	+0.64*** (59)

*, **, *** = probabilities associated to Pearson correlation coefficients at $p<0.05$, $p<0.01$ and $p<0.001$, respectively.
n.s. = $p>0.05$
1/ In parenthesis: number of observations, NDF=neutral detergent fibre, ADIF=acid detergent fibre, bCT=bound condensed tannins, IADF=indigestible acid detergent fibre, PP=polyphenols, IVDM=*in vitro* dry matter digestibility, CT=condensed tannins, N=nitrogen

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.

Soil crusting and sealing in Andean cropping systems: physical and chemical factors

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Soil erosion, run-off and its problematic consequences have been recognized by farmers in Latin America, but knowledge and means to combat this phenomenon are unavailable. Until now, soil crusting and sealing has received minimal scientific attention in the Andean zone of South America. Although the contribution of soil crusting and sealing to soil erosion are widely accepted, there have been long discussions of the causes such as 1) the splash impact of raindrops coupled with low aggregate stability; 2) the dispersion of clays through chemical agents; and 3) both physico-chemical processes.

Field research was conducted in Santander de Quilichao at the CIAT Research Station, Department of Cauca in southwestern Colombia (3°6'N, 76°31'W, 990 m.a.s.l). The area is characterized by moderate to high erosion potentials due to its undulating relief with some steeper slopes, a strong effect of soil and crop management, and due to an extreme climatic impact (mean annual rainfall: 1756 mm, rain intensity: up to 330 mm h^{-1}). Trials were installed in 1986 on an amorphous, isohyperthermic oxic Dystropept (US soil taxonomy), which is a ferralic Cambisol according to the WRB. It is developed from fluvially translocated, weathered volcanic ashes from the local volcanoes Puracé and Sotará.

The measurements of penetration resistance were made in eight cassava-based cropping systems and one bare fallow treatment on 27 Erosion Experimental Plots according to Wischmeier and Smith (1978) on slopes with an inclination of 7 to 13%. The plots had been in use since 1986 through a consecutive research project. They were designed as a completely randomized block with three repetitions. The randomized block design was selected to manage local soil heterogeneity

All nine treatments were grouped into three categories to evaluate the specific research questions, such as the impact of chicken manure on soil crusting, the influence of conservation systems on structural development, and the effects of different tillage practices on soil structure and system stability:

1. The **manure group** included cassava 8 t ha^{-1} chicken manure (T5), cassava 4 t ha^{-1} chicken manure (T2), and cassava monoculture (T3).
2. The **conservation group** consisted of cassava 4 t ha^{-1} chicken manure (Vetiver) (T6), cassava + *Chamaechrista rotundifolia* (T7), and cassava rotation (T8).
3. The **tillage group** included bare fallow (T1), cassava minimum tillage (T4), and cassava intensive tillage (T9).

Results of Penetrometer and Torvane measurements in 2000 and 2001 showed a significant climatic influence on penetration resistance and shear strength. In wet soil conditions, penetration resistance and shear strength generally remained at a low level. In contrast, when the soil dried out penetration resistance and shear strength increased in some treatments. This observation led to the division of four distinct climatic periods (January-March dry season, March-beginning of May strong rainy season, May-September strong dry season, September-December rainy season). In 2000, the climatic seasons followed exactly this long-term trend whereas in 2001, the rain amount was extraordinary low especially in the period from March to May. Concerning shear strength in 2000, T5 was significantly different in the rainy season from T2 but not from T3. In the dry season no further significant differences were noted. T6 (conservation group) presented a significantly higher shear strength only in the rainy season. The tillage group was characterized by the significantly highest shear strength of T4 followed by T1 in the rainy and dry season.

No significant differences were found in the year 2000 in the major aggregate classes (>6.3 mm and >2 mm) and in the three minor aggregate classes (>0.25 mm, >0.125 mm, and <0.125 mm). In the aggregate class >4 mm, the T3 and T1 treatments contained a significantly lower amount of aggregates than T4. In the class >1 mm, a significant difference between T4 and T9 as well as T1 was found. In the class >0.5 mm, T3 presented significantly lower amounts of aggregates than T4.

In 2000, T4 showed the significantly highest aggregate stability in the biggest aggregate class >6.3 mm (55.5 %) compared to the other treatments, with the exception of T5, T8, and T6.

Results of soil erosion and run-off obtained in both years revealed significant differences in 2000 between treatments. T1 generated the significantly highest amounts of run-off in all treatments with the exception of T9 and T4. The run-off rate was also the highest in T1. Similar to run-off, was soil erosion higher in 2000 than in 2001 due to more erosive rainfalls in the year 2000 and due to lower precipitation in 2001. The highest amount of soil erosion was found in T1. It presented such a marked disparity to the other results that it had to be excluded from statistical analysis as normality criterion could not be reached.

In the year 2000, highest total nitrogen (N) was found in T4, whereas T1 revealed the significantly lowest N content. Highest potassium (K) was found in T4 and T2. Significantly lower K was found in T8 and T3 and the lowest amount of K was found in T1. The analysis of calcium (Ca) showed the highest rate in T4, followed by T2 and T8. The lowest Ca was found in T1. Similar results were obtained for magnesium (Mg). The significantly highest amounts of aluminum (Al) were found in T1 and the lowest in T4. Iron (Fe) presented no real differences, and manganese (Mn) was significantly highest in T4, T2, and T5. In contrast, the significantly lowest Mn was found in T1. T4 presented the highest N content and was significantly different from T5. The highest soluble P was found in T1 which was significantly different from T3. Regarding soluble K, it was found out that T4 differed notably from T8 and T1. Similar results were found in Ca and Mg where T4 showed markedly higher values than T1. The investigation of soil reaction revealed significant differences in most treatments with the exception of T5 and T8. The lowest pH was measured in T1 (pH 3.8) followed by T3, T5 and T8, T2 and finally T4 (pH 5.2). The pH-values were higher in the cultivated treatments due to the application of dolomitic lime. Exceptional results showed T3 which presented only a pH of 4.3.

The influence of soil organic matter (SOM) on the development of soil crusting and sealing has widely been investigated. Statistical analysis over the course of two years of investigation revealed a significantly lower SOM-content in T1. The mean annual soil loss of about 180 t ha^{-1} during the research period from 1987 to 2001, and high surface run-off is the reason for this accelerated soil organic matter depletion. In contrast, T4, T8, and T7 maintained soil fertility owing to the contribution of organic material, i.e. mulch, grass roots and legume parts, to the SOM-pool. Therefore, the significantly highest SOM was measured in T4 (7,1 %) and T8 (7.0).

Results showed a significant correlation between Electrical Conductivity (EC) and penetration resistance and shear strength, as well as some elements in the treatments. The overall EC was highest in T4 (0.61 mS cm^{-1}), being significantly different from T5 (0.38 mS cm^{-1}). No real differences were found within the chicken manure plots, however T5 was significantly different from T8. Lowest EC was found in T1 (0.20 mS cm^{-1}) followed by T3 (0.26 mS cm^{-1}). A strong correlation between penetration resistance and shear strength was found in February 2001 and in August 2001. Shear strength correlation to EC was higher in Feb 2001 which points to the importance of the date of application of fertilizers and manures for the degree of correlation.

Results on soil physical characteristics showed marked effects of chicken manure on the cropping systems. T5 and T6 demonstrated structural changes in both years. In the rainy seasons there were no real penetration restrictions. In contrast, its superficial soil structure altered in both dry seasons, and changed from a well structured soil to a superficially crusted soil. This phenomenon can be attributed to the effects of chemical dispersion on the soil structure which led to a destabilization of the superficial aggregates due to isomorphous replacement of elements of this nutrient rich manure. The development of soil crusting and sealing could be clearly distinguished from natural soil hardening due to aggregation by field observations in both treatments. Chicken manure treatments did not differ significantly from T4 in soil aggregation but revealed notably lower amounts of aggregates in the class >6.3 mm and higher amounts of aggregates in the classes >1 mm, >0.5 mm and > 0.25 mm. The positive soil effects of chicken manure on soil fertility are counteracted by extreme structural degradation.

Conclusions

- Investigating the physical and chemical predisposition of Andean cropping systems towards the development of soil crusts and seals revealed that excessive organic manuring and tillage practices negatively affected the soil's physical and chemical status. As a consequence soil crusting and sealing occurred in these treatments.
- Conservative soil treatments like minimum tillage and crop rotations improved the physical soil structure and chemical fertility. Consequently, soil crusting and sealing was not observed in these treatments. Soil erosion as a final monitor was strongly reduced. Therefore, these treatments should be strongly recommended to the farmers by local extensionists.
- There is still a need for additional research to find out appropriate amounts of organic and mineral fertilizers on Andean hillside farming systems. Soil crusts and seals developed on steeper slopes in this research area should also be an important factor to be investigated in order to minimize soil degradation in this area.

Wetting and drying processes in two textural savanna Oxisols in the Colombia Llanos

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It is generally believed that Oxisols have excellent structural conditions that give them a high infiltration capacity and good drainage. However, different studies conducted in the flat Colombian Savannas (Llanos) have shown that these soils after being disturbed by machinery lose part of their infiltration capacity, increase runoff, and lose nutrients. A study of water infiltration capacity in a wide range of soil textures showed that infiltration was closely related to the percentage of sand in these soils. Soils with sand content inferior to 50% presented low infiltration capacity, while those with more than 50% of sand had moderate infiltration capacity. In these studies water infiltration was inversely correlated with soil strength measured in the upper 0-3 cm of soil. Values that are higher than 45 KPa at field capacity showed restrictions to water infiltration. Although there have been numerous studies on water infiltration, very few have documented the processes of wetting and/or drying of the soil over time. The purpose of this study was to evaluate during the dry season, how different amounts and frequencies of applying water, affects the distribution of water in the soil profile of two contrasting textural soils: heavy and light. The study was conducted on the Matazul Farm, township of Puerto López (lat. 4° 5' and long. 72° 58'). The soils are classified as Typic Haplustox Isohyperthermic kaolinitic. The soils are acid with Al saturations higher than 80%, base-saturation percentage less than 15% and low phosphorus content (2.3 ppm). The mean annual rainfall of the farm is 2251 mm, with a unimodal distribution from April-Nov. The potential evapotranspiration of the zone is 112 to 123 mm/mo for the rainy and dry seasons. Solar radiation varies from 4.47 to 4.77 Kw-h/m^2, respectively.

The purpose of this research was to study how in a dry soil profile of a natural savanna, water is redistributed after irrigation. Different amounts of water were applied every day (continuous application) or every other day (alternating application) to experimental units of 1 m × 1 m of soils with different textures: light (58.6% of sand content and 24.6% of clay) and heavy (29.7% of sand and 40.9% of clay). The evaluation was made during the dry period (11 Feb.-3 Mar.) after 45 dry days, having two field replications in a completely randomized design. To each experimental unit different amounts of water were applied at a rate of 0.5 L/min. Nine treatments were used, they are presented in Table 8. The basic application rate for one day was 20 L/m^2. The 20 liters were applied in four 5-L dosages, every 10 min, to prevent waterlogging and runoff.

Table 8. Treatments applied to the two soil textures of an undisturbed native savanna soil.

Details of Treatments	**Treatments**								
	Application on Continuous Days					**Application on Alternating Days**			
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**
No. of 20-L dosages applied	1	2	3	4	5	2	3	4	5
Total water applied (L/m^2)	20	40	60	80	100	40	60	80	100
Control	(T0): No water applied								

Treatments 1-5 received 1, 2, 3, 4 and 5 basic rates, respectively, on continuous days, corresponding to 20, 40, 60, 80 and 100 L of water/m^2. Treatments 6-9 received 2, 3, 4 and 5 basic rates on alternating days, corresponding to 40, 60, 80 and 100 L/m^2. After finishing each treatment, the gravimetric moisture was measured at different depths (0-10, 10-20, 20-30 and 30-40 cm) and days 1, 2, 3, 4, 6, 8, 10 and 12, taking two samples of soil for each depth stratum in each experimental plot (i.e., 4 samples/treatment and depth). An initial sampling was done to determine OM content, bulk density (metal cubes 10 × 10 × 10 cm) and particle density.

Particle-density values maintained a relatively constant value of about 2.62 Mg.m^{-3}, showing no-differences for soil texture or depth in the soil profile. The bulk-density values of the light soil were significantly higher at all depths, than those in the heavy-textured soil. Therefore, the heavy soil had higher values of total porosity. On the other hand, the heavy soil had almost twice the OM content as the light soil.

Table 9 shows the percentages of gravimetric moisture content in the light soil one day (field capacity) after the last application of water. It can be observed, that the maximum amount of water occurred when 100 L were applied in a continuous way. In this treatment moisture content was significantly higher than in the others treatments up to a depth of 20 cm. There were no significant differences with the application of 40, 60 or 80 L/m^2. Moisture content values during the first day were higher than these of the control (6.54, 7.20, 7.52 y 8.56).

Table 9. Percent of gravimetric moisture content (%) in the light-textured soil 1 day after application of the rates in the respective treatments.

Rates Applied (L/m^2)	Sampling Depth (cm)[1]			
	0-10	10-20	20-30	30-40
	------------------- Gravimetric moisture content (%) -----------------			
Continuous				
20	9.48 b	9.48 b	---	---
40	10.29 ab	10.29 b	10.68 a	---
60	10.01 b	10.01 ab	10.30 bc	---
80	9.71 b	9.71 ab	10.67 ab	10.64 a
100	11.02 a	11.02 a	11.07 ab	10.08 ab
Alternating				
40	9.48 b	9.48 b	(7.54) d	---
60	9.49 b	9.49 b	(7.90) d	(6.56) c
80	9.20 b	9.20 b	9.57 c	(7.91) c
100	9.45 b	9.45 b	10.03 bc	8.38 bc
Savanna (Control)	6.54 c	7.20 c	7.52 c	8.06 bc

[1] Means with the same letter in the same row are not significantly different ($P<0.05$) according to Duncan's test.
---Samples could not be taken with the borer due to the hardness of the soil; also indicates that the water was not sufficient to wet the soil.
( ) Gravimetric moisture values lower than the dry savanna (control).

In general the continuous-application treatments had higher gravimetric moisture contents than the alternating- application treatments, which shows that if the soil has higher moisture content, it also has an increased capacity to transmit water. The results from Table 9 also showed that some of the treatments where less water was applied, did not penetrate to more than 20 or 30 cm soiuldepth. This is due to the fact that the amount of water used was not enough to penetrate to these depths. In the heavy-textured soil the percentages of gravimetric moisture content were higher than that of the light-texture soil. The 100-L continuous-application treatment had higher gravimetric moisture content at all depths. It was also found in this soil that the amount of water used to moist the soil in some of the treatments was not enough to penetrate the soil to depths of 20-30 cm.

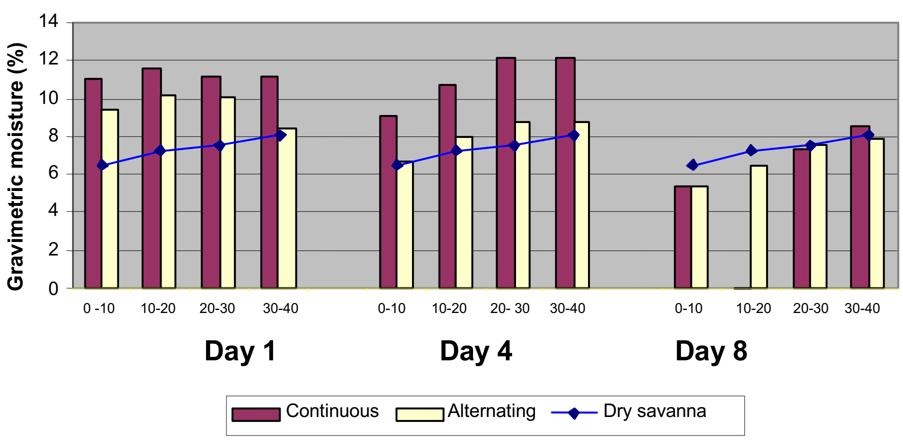

Figure 10. Percent gravimetric moisture by soil depth in a light-textured soil, 1, 4 and 8 days after applying five rates of water (20 L each) continuously or on alternating days.

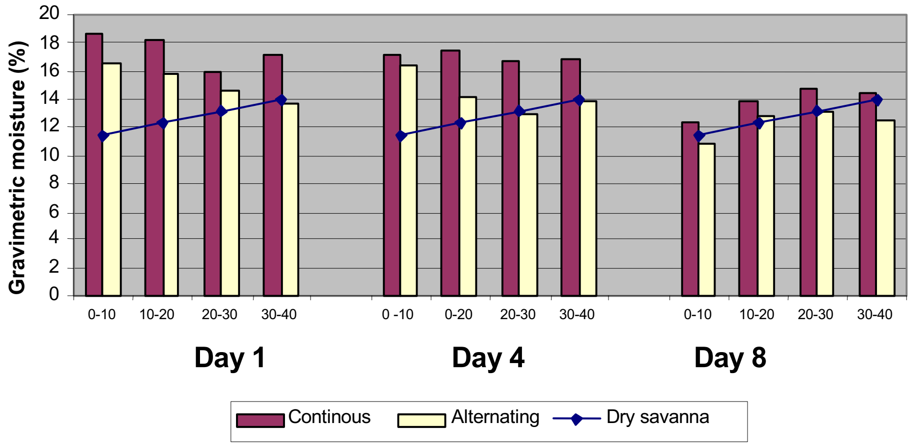

Figure 11. Gravimetric moisture content (%) in a heavy-textured soil, by depth, 1, 4 and 8 days after applying 5 rates of water (20 L each) continuously or on alternating days.

Figures 10 and 11 show the gravimetric moisture content for the light and heavy textures, respectively, for days 1, 4 and 8 after applying 100-L/m^2 treatments with continuous and alternating applications vs the savanna control. For both textures a higher gravimetric moisture content was observed in the continuous treatments than in the alternating treatments. Greater differences were found in the gravimetric moisture content between continuous vs alternating treatments in the heavy-textured soils than in the light-textured one. On day 8, the gravimetric moisture content in the light texture was lower than that for the savanna (control); while in the heavy texture a slightly higher gravimetric moisture content was maintained in the continuous treatment over the control. The data indicate clearly how the heavy-textured savanna maintains a higher gravimetric moisture content level over time than the light texture, which can be associated with a higher OM content, finer particles, greater capacity to store water and less macroporosity.

Conclusions

- The methodology used was sufficiently sensitive to detect the dynamics of drying the soil and could prove useful for understanding and developing water-flow models in the soil profile; nevertheless, it is necessary to eliminate the loss of water due to the lateral flow in the adjacent zone that did not received water.
- The light-textured savanna soils had a higher bulk density, lower total porosity and lower OM content than the heavy-textured soils at all depths. The latter soils had a higher proportion of micropores, which permitted more water retention, but their hydraulic conductivity was slower.
- At the field level, the wilting point was higher in heavy textures than in light, at both the gravimetric moisture (12.7 vs 7.3%) and volumetric moisture content levels (16.5 vs 10.8%). Similarly, there was a greater field capacity in heavy- than in light-textured soils: 17.5% and 10.9% and in a volumetric moisture content base 22.7% and 16.2%, respectively.
- The available water for plants was fairly similar in the two textures (6.2 and 5.4% for the heavy and light textures, respectively). These values are considered limiting for adequate plant growth and development.
- The evapotranspiration rates in the 100-l/m^2 treatment were estimated at 13.6 and 16.4 mm/day for the continuous and alternating systems, respectively.
- In the light-textured soil the available water was depleted in 4 days; in the heavy soils, after 8 days of drying. The treatments with continuous application had higher percentages of gravimetric moisture content and volumetric moisture content and theoretical available water than the alternating treatments.

Susceptibility to compaction of improved Oxisols in the Eastern Plains of Colombia

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Determining the degree of soil compaction is very important to define its quality in terms of its capacity for crop production. It is necessary to use parameters that characterize it and that give values that can be compared among different soil types. In general, there is a scarcity of predictive methodologies capable of indicating to what extent a soil can be compacted without having an adverse effect on agricultural production. It is accepted that the methodology of determining relative bulk density (susceptibility to compacting or compacting level) satisfies this need. The "compacting level" is defined as the percentage of the ratio between the initial and the final bulk densities of a volumetric soil sample equilibrated to a suction of 7.5-10 KPa (field capacity), and subjected to an uniaxial confined pressure of 200 KPa. This percentage expresses the maximum value of the ratio (ℓai/ℓaf – initial bulk density of the soil/ final bulk density) that a soil can reach and relates it, according to Häkansson (1986), to a critical good level of 87%. Soils with values higher than this critical level are less adequate for root growth and for crop production. Values close to 100% indicate that the soil is already compacted and that the probabilities of agricultural success are low. This methodology is based on the use of large soil samples, but it can also been used with small samples. This article presents and discusses the results obtained in an Oxisol of the Eastern Plains, when applying this methodology to a soil-improvement trial.

The experiment was established on the Matazul Farm (4º 9' 4.9" N, 72º 38' 23". O), located in the municipality of Puerto López, Meta Province, at an elevation of 260 m.a.s.l. The zone has two clearly differentiated climatic periods: a rainy season that goes from March until December and a dry season from December until the first week of April. The average annual temperature is 26.2ºC. The zone has an average annual rainfall of 2719 mm, a potential evapotranspiration of 1623 mm and a relative humidity of 81%. The soil is classified as Isohyperthermic Kaolinitic Typic Haplustox in USDA soil classification system. This trial was initiated in 1996; the measurements determinations that correspond to this paper were made in 1999.

Susceptibility to compaction was made in plots of an experiment, designed to improving the soil physical condition of soils with high bulk density. The following treatments were used: (i) vertical tillage (use of chisel) to a depth of 30 cm at different intensities: 1, 2 and 3 chisel passes with legs separated at 0.60, 0.30 and 0.15 m to obtain three degrees of soil loosening. These plots were sown in a rotation system of rice/soybeans. The other treatments involved the use of two chisel passes and were sown with grass alone pasture, legumes alone and a combination of grass + legume to be incorporated early (at the end of the rainy season) or late (at the end of the dry season) into the soil, to study the effect of the season in the incorporation of residues for improving soil physical conditions.

Experimental plots of 30×50 m were established and were random distributed at the beginning of the experiment 1996A. After three years 1999B, in each plot three pits of 0.5×0.5×0.5 m were dug, and undisturbed soil samples were taken in cylinders (50×50 mm) at four depths: 0-10, 10-20, 20-30 and 30-40 cm using four replications. Twelve samples were taken per treatment per depth. The parameters evaluated included bulk density (initial and final) and susceptibility to compaction. The samples were saturated and then submitted to equilibrium at a suction of 75 cm (field capacity, initial volume) and then subjected an uniaxial pressure equivalent to 200 KPa in a Proctor apparatus (final volume). The ratio between the initial and final bulk densities permitted the determination of the percentage of "susceptibility to compaction" or "compacting level".

In comparison to native savanna, no-intervened soil, that presented values ranging from 1.43-1.53 ($Mg.m^{-3}$) at the depths studied (Table 10), the values found in the treatments were lower, indicating that the soil had improved as a result of the treatments. SuiTable low bulk densities are of great importance for soil management in this type of soil as they are indicative of factors that regulate root growth, infiltration, and water movement in the soil, which in turn affects nutrient availability in soil and nutrient acquisition by plants. Given that a good bulk density values for crop production in mineral soils ranges from 1.10-1.30

Table 10. Statistical comparisons among treatments based on depth of treatment with some physical characteristics of the soil in the Cultural Profile trial, Matazul, 1998.

Depth (cm)	Treatments	Initial Bulk Density (g /cm^3)	Final Bulk Density (g /cm)^3	Compacting Level (%)	Residual Porosity (%)
0-10	1 pass chisel (T1)	1.19 b	1.43 a	83.26 b	16.73 a
	2 passes chisel (T2)	1.23 b	1.48 a	82.86 b	17.13 a
	3 passes chisel (T3)	1.22 b	1.47 a	83.60 b	16.40 a
	Early incorporation residue				
	Grass (T4)	1.16 b	1.40 a	82.86 b	17.13 a
	Grass + legume (T5)	1.23 b	1.45 a	84.60 b	15.40 a
	Legume (T6)	1.12 b	1.41 a	79.40 b	20.60 a
	Late incorporation residue				
	Grass (T7)	1.11 b	1.41 a	78.73 b	21.26 a
	Grass + legume (T8)	1.21 b	1.48 a	81.46 b	18.53 a
	Legume (T9)	1.12 b	1.42 a	78.86 b	21.13 a
	Native savanna (T10)	1.43 a	1.49 a	95.60 a	4.40 b
	$LSD_{0.05}$	0.13	0.08	6.68	6.68
10-20	1 pass chisel (T1)	1.41 abc	1.54 a	91.40 ab	8.60 bc
	2 passes chisel (T2)	1.29 c	1.53 a	84.53 bc	15.46 ab
	3 passes chisel (T3)	1.32 bc	1.51 a	87.73 abc	12.26 abc
	Early incorporation residue				
	Grass (T4)	1.30 c	1.48 a	88.00 abc	12.00 abc
	Grass + legume (T5)	1.29 c	1.78 a	76.33 c	23.66 a
	Legume (T6)	1.33 bc	1.53 a	87.00 abc	13.00 abc
	Late incorporation residue				
	Grass (T7)	1.32 bc	1.49 a	88.33 abc	11.66 abc
	Grass + legume (T8)	1.45 ab	1.53 a	94.66 ab	5.33 bc
	Legume (T9)	1.29 c	1.44 a	89.73 ab	10.26 bc
	Native savanna (T10)	1.50 a	1.55 a	97.33 a	2.66 c
	$LSD_{0.05}$	0.12	0.34	11.08	11.08
20-30	1 pass chisel (T1)	1.45 ab	1.60 a	90.66 a	9.33 a
	2 passes chisel (T2)	1.42 ab	1.62 a	87.53 a	12.46 a
	3 passes chisel (T3)	1.38 ab	1.55 ab	88.53 a	11.46 a
	Early incorporation residue				
	Grass (T4)	1.34 ab	1.58 ab	85.00 a	15.00 a
	Grass + legume (T5)	1.40 ab	1.59 a	88.13 a	11.86 a
	Legume (T6)	1.38 ab	1.55 ab	89.00 a	11.00 a
	Late incorporation residue				
	Grass (T7)	1.28 b	1.46 b	87.53 a	12.46 a
	Grass + legume (T8)	1.34 ab	1.52 ab	88.06 a	11.93 a
	Legume (T9)	1.38 ab	1.55 ab	88.73 a	11.26 a
	Native savanna (T10)	1.53 a	1.57 ab	97.60 a	2.40 a
	$LSD_{0.05}$	0.20	0.11	11.11	11.11
30-40	1 pass chisel (T1)	1.54 ab	1.64 a	93.66 a	6.33 b
	2 passes chisel (T2)	1.51 ab	1.63 a	92.13 ab	7.86 ab
	3 passes chisel (T3)	1.41 ab	1.57 a	89.73 ab	10.26 ab
	Early incorporation residue				
	Grass (T4)	1.44 ab	1.59 a	90.80 ab	9.20 ab
	Grass + legume (T5)	1.57 a	1.63 a	96.20 a	3.80 b
	Legume (T6)	1.49 ab	1.60 a	92.86 ab	7.13 ab
	Late incorporation residue				
	Grass (T7)	1.31 b	1.52 a	85.33 b	14.66 a
	Grass + legume (T8)	1.51 ab	1.61 a	94.26 a	5.73 b
	Legume (T9)	1.49 ab	1.62 a	91.93 ab	8.06 ab
	Native savanna (T10)	1.52 ab	1.63 a	93.00 ab	7.00 ab
	$LSD_{0.05}$	0.21	0.14	7.03	7.03

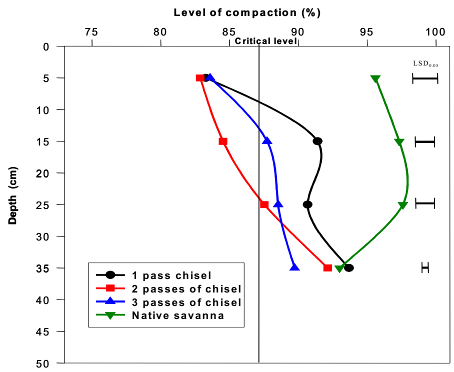

Figure 12. Compaction levels in the rice/soybean rotation at different soil depths in relation to the tillage and the critical level.

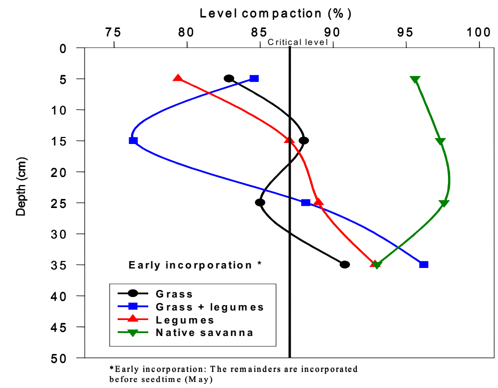

Figure 13. Compaction levels at different soil depths in the early incorporation treatments in relation to the critical level.

$Mg.m^{-3}$, that 1.4-1.6 $Mg.m^{-3}$ inhibit root growth and values of about 1.8 $Mg.m^{-3}$ suppress it, the values obtained in the first depth (0-10 cm) of the treatments were adequate for good root development. The differences between the treatments and the native savanna were highly significant ($LSD_{0.05}$), but there was no statistical difference among the treatments, therefore, it is necessary to implement vertical tillage in these soils in order to obtained a good physical conditions for crop production.

The final bulk densities are also shown in Table 10. At all depths, the final bulk density was statistically similar to that of savanna. Therefore, it can be affirmed that under the methodological conditions used, the treatments can reach values equivalent to those found in the native savanna, that restrict root growth.

The third column of Table 10 presents the susceptibility of the different treatments to compaction, expressed in terms of percentage. The term "susceptibility to compaction," also known as "compacting level" or relative bulk density, is a good parameter for determining the degree of compaction that a soil can support without affecting significantly its physical condition for producing crops. The values found under field condition are very important for comparing the actual extent of soil compaction, in relation to the obtained under laboratory condition, making it possible to judge whether the soil under field conditions presented a good or deficient soil physical condition for crop production. This allows being in a position to decide more precisely the type of physical improvement that the soil requires.

The analysis of the results show that at the first depth (0-10 cm), the values found in the treatments were statistically inferior to those found under the condition of native savanna (natural state). This indicates that the treatments had improved the soil physical condition. For interpretation of the results it should be taken into account that a value of 100% indicates that the soil is already compacted, as the field bulk density is equal to the bulk density of the soil submitted to the confined pressure. In the case of the native savanna at this depth, the value was 95.1%, which indicates that remain 4.9% of the soil volume, to be totally compacted.

In the case of the native savanna, values were always higher than the critical 87% level, indicating that the original physical condition of these soils is not suitable for planting cash crops and that vertical tillage needs to be applied before these soils can be used for agriculture (Figure 12). Under the late incorporation of residue treatment, biological treatments with grass and legumes with two passes of the chisel, had lower values (Figure 13).

After the confined pressure of 200 KPa, there still remains a percentage of porosity, referred here as "residual porosity." These values are shown in the last column of Table 10. As this parameter is complementary to the compacting level, the higher its value, the soil has a better physical condition for root development and is more resistant to compaction. The minimum acceptable value could be around 15%. Values below this percentage indicate that the soil is susceptible to compaction and that the support capacity (maximum load that a soil at field moisture content can support for preparation, without being deformed) of the soil is low. Values higher than 15% indicate that the soil is resistant to compaction and has a good machinery supporting capacity. The values for the native savanna were below this critical level to the depths studied. They ranged from 7.0% to 2.4%. The values found in the treatments were higher to a depth of 30 cm, leading to the conclusion that vertical tillage is essential for correcting these soils.

Conclusions

- The Oxisols of the Colombian savannas in their natural condition have high compacting-level values, ranging from 93-97% (a value equal to 100 indicates that the soil is already too compacted for farming and production of pastures), to a depth of 40 cm. Under these conditions, they are not apt for growing crops.
- These values can be lowered to "adequate" levels by using vertical tillage (2 passes of the chisel) in combination with planting improved tropical forage grasses and/or legumes.
- The methodology used in this research proved to be sensitive to the changes produced by vertical tillage in the soil physical conditions; therefore it is recommended as an indicator of the actual condition of soil compaction.

Effects of soil crusting on infiltration measured by a mini-rain-simulator in Colombian hillside cropping systems

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The aim of this study was to identify soil structural degradations in nine cropping systems of the Andean hillsides and to investigate their influence on water infiltration. Field research was conducted in Santander de Quilichao at the CIAT Research Station, Department of Cauca in southwestern Colombia (3°6'N, 76°31'W, 990 m.a.s.l). Santander de Quilichao is located at the southern end of the Cauca Valley. Trials were established on an amorphous, isohyperthermic oxic Dystropept, which is a ferralic Cambisol. It is developed from fluvially translocated, weathered volcanic ashes from the local volcanoes Puracé and Sotará.

The measurements of penetration resistance were made in nine cropping systems on 27 Standard Erosion Experimental Plots on slopes with an inclination of 7 to 13%, 14 years after the experiment was establish as a completely randomized block in three repetitions. Infiltration was measured using a mini-rainsimulator described by Amézquita (1999), irrigating a defined soil surface area (32,5 cm × 40 cm) with a distinct amount of rain (90 ± 5 mm h^{-1}). The simulator was installed about one meter inside the plot boundary. Leaves, grass particles and weeds were carefully removed from the soil surface before measurement. After calibrating the simulator by collecting and measuring a defined rain period of 1 min, a specific rain event of 50 min was carried out. The construction of this simulator enabled the collection of run-off periodically (every 5 min). The difference between irrigated rain and run-off was defined as infiltration. Measurements of infiltration were conducted in both rainy seasons (April/May and October/November) in 2000 and 2001, respectively. Each measurement was repeated nine times per treatment (three time per plot) to account for the spatial variability. Field measurements of penetration resistance were taken with a pocket Penetrometer. Six measurement points were established on each plot, two at each end and two in the middle part of the plot at a one-meter distance from the plot boundary. The penetrometer was inserted into the soil surface with a needle of about 4 cm. Penetration resistances were measured by pushing the penetrometer vertically into the soil surface. Four readings were taken at each measurement point and their mean noted.

Considering the varying results of penetration resistance in the year 2000 (Table 11), four distinct time periods could be observed (January-March, March-beginning of May, May-September, September-December). These periods obviously coincided with the rainy and dry seasons. The rainy season March/May 2000 and the strong dry season July/August 2000 were of special interest. When the soil was wet, penetration resistance generally remained at a low level. In contrast, when the soil dried out penetration resistance increased in some treatments.

In 2000, outstanding results in penetration resistance measurements were found in T4 revealing 46.4 kg cm^{-2} in August (Table 11). The cassava chicken manure treatments (T2, T5 and T6) showed a similar trend in the rainy and dry season. Highest penetration could be measured in T6 (19.6 kg cm^{-2} in August), followed by T5 (16.2 kg cm^{-2} in July) and T2 (12.9 kg cm^{-2} in August). T7 and T8 showed similar results but had comparably lower penetration resistance in the major dry season. Exceptional results were found in T9 where seasonal changes had minimal effects. In September 2000, T1 had to be newly prepared to seedbed conditions according to USLE-recommendations of Wischmeier and Smith (1978) and, therefore, results of T1 in September and October were not included in the analysis.

Table 11: Influence of treatment on monthly averaged penetration resistance (kg cm^{-2}) in the top 4 cm layer in 2000 and 2001, Santander de Quilichao.

No	2000	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov
T1	Bare fallow	3.6 a	3.9 a	2.8 b	8.3 b	8.4 bc	11.2 ab	9.6 ab	NIL	NIL	0.7 a
T2	Cassava 4 t ha^{-1} chicken manure	3.0 a	3.0 a	2.2 ab	4.3 a	5.1 ab	8.6 ab	12.9 ab	4.1 a	4.8 a	3.7 bc
T3	Cassava monoculture	2.7 a	3.0 a	1.8 a	4.4 a	4.3 ab	6.0 a	9.1 ab	4.1 a	4.3 a	3.3 bc
T4	Cassava minimum tillage	8.3 b	4.4 a	2.9 b	8.4 b	12.4 c	22.3 c	46.4 c	24.5 b	28.6 b	9.5 d
T5	Cassava 8 t ha^{-1} chicken manure	3.9 a	3.5 a	2.3 ab	4.5 a	7.6 ab	16.2 bc	13.0 ab	5.6 a	6.2 a	4.3 c
T6	Cassava 4 t ha^{-1} chicken manure (V)	3.4 a	3.1 a	2.4 ab	5.1 a	5.2 ab	8.7 ab	19.6 b	5.0 a	6.3 a	4.2 bc
T7	Cassava +Ch. rotundifolia	2.9 a	2.6 a	2.3 ab	5.3 a	5.5 ab	9.4 ab	12,6 ab	5.1 a	6.0 a	3.8 bc
T8	Cassava rotation	2.4 a	1.9 a	1.6 a	4.0 a	4.8 ab	9.8 ab	13.8 ab	4.7 a	4.6 a	3.1 b
T9	Cassava intensive tillage	2.6 a	2.6 a	1.9 a	3.8 a	3.6 a	5.0 a	4.2 a	3.7 a	3.6 a	3.3 bc
No	**2001**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**
T1	Bare fallow	2.4 a	1.6 a	1.5 a	2.0 a	1.8 a	3.9 a	5.1 a	4.1 a	2.7 a	3.0 ab
T2	Cassava 4 t ha-1 chicken manure	3.0 ab	2.2 a	1.9 a	2.1 a	2.4 a	5.0 ab	6.0 a	4.6 a	2.7 a	3.0 ab
T3	Cassava monoculture	3.0 ab	2.3 a	2.0 a	2.3 a	2.1 a	4.4 ab	5.9 a	4.3 a	2.9 a	3.1 ab
T4	Cassava minimum tillage	8.5 c	7.7 b	4.2 b	4.3 b	6.0 b	15.3 c	45.5 b	37.4 b	10.6 b	8.5 c
T5	Cassava 8 t ha-1 chicken manure	4.0 b	2.5 a	2.0 a	2.5 a	2.6 a	7.4 b	12.3 a	6.6 a	3.3 a	3.2 ab
T6	Cassava 4 t ha-1 chicken manure (V)	3.3 ab	2.2 a	2.0 a	2.2 a	2.6 a	5.4 ab	7.3 a	4.9 a	2.9 a	3.2 ab
T7	Cassava +Ch. rotundifolia	4.1 b	2.8 a	2.2 a	2.5 a	2.6 a	5.0 ab	6.5 a	5.1 a	2.7 a	2.6 a
T8	Cassava rotation	3.7 ab	2.3 a	2.4 a	3.0 a	4.3 ab	6.6 ab	10.8 a	7.9 a	4.9 a	5.4 b
T9	Cassava intensive tillage	2.5 a	2.1 a	1.7 a	2.0 a	2.0 a	3.8 a	5.0 a	3.8 a	2.3 a	2.9 ab

[1]means followed by the same letter in column are not significantly different at p≤0.05 probability level, Tuckey's-test

Notes: Treatments with chicken manure in 2000 and 2001= T2, T5, T6; Treatments with mineral fertilizer = T4, T7, T8 and T9; Treatments without fertilizer, T1, and T3. Rototiller treatment (1x) was carried out in T1-T3, T5-T8; intensive rototiller (5x) in T9; no rototiller treatment was carried out in T4

Results of the two measurements in 2000 revealed that T4 and T8 showed the highest final infiltration after an averaged rain intensity of 90 mm h^{-1} (±5 mm), the lowest final infiltration was found in T5 and T3. The mean final infiltration reached only 42.2 mm h^{-1} in T5 and 42.7 mm h^{-1} in T3, respectively. In contrast, T4 presented a mean final infiltration of about 76.2 mm h^{-1}). Investigating the curves of all treatments in 2000 showed stronger decrease in slope in the chicken manure treatments (T2, T5, and T6) as well as T1 and T3. Statistical analysis at p≤0.05 did not reveal significant differences because of high spatial variability between measurement points (Tables 12 and 13). At a higher α-level, $p \leq 0.10$, significant differences between T4 and T5 were discovered. Additionally, final run-off was statistically analyzed at $p \leq 0.10$. In the above mentioned treatments, the significantly highest final run-off was measured in T5 and T3. In contrast, the lowest final run-off was observed in T4. Taking the lower α-level of $p \leq 0.05$ into account, no further significant differences were found.

Table 12. Effect of treatment on final infiltration and final run-off, (Apr and October 2000, Santander de Quilichao.

No	Treatment	2000			
		Final infiltration (mm h^{-1})	**Standard deviation**	**Final run-off (mm h^{-1})**	**Standard Deviation**
T1	Bare fallow	52.1 a[1]	18.2	38.3 a	17.6
T2	Cassava 4 t ha^{-1} chicken manure	54.8 a	19.1	38.0 a	19.5
T3	Cassava monoculture	42.7 a	16.2	49.2 a	18.8
T4	Cassava minimum tillage	76.2 a	16.2	15.6 a	13.2
T5	Cassava 8 t ha^{-1} chicken manure	42.2 a	11.4	49.6 a	10.3
T6	Cassava 4 t ha^{-1} chicken manure (V)	49.6 a	15.9	41.0 a	16.9
T7	Cassava + Chamaecrista rotundifolia	56.6 a	23.2	36.7 a	21.6
T8	Cassava rotation	70.9 a	16.4	19.7 a	14.9
T9	Cassava intensive tillage	46.5 a	11.3	45.3 a	11.3

[1] means followed by the same letter in column in 2001 are not significantly different at $p \leq 0.05$, Tukey's–test.

Table 13: Effect of treatment on final infiltration and final run-off, May and October 2001, Santander de Quilichao.

No	Treatment	2001			
		Final infiltration (mm h^{-1})	**Standard deviation**	**Final run-off (mm h^{-1})**	**Standard deviation**
T1	Bare fallow	54.2 ab[1]	6.8	36.4 cde	8,9
T2	Cassava 4 t ha^{-1} chicken manure	63.9 bcd	15.2	28.1 bcd	13,6
T3	Cassava monoculture	38.8 a	6.2	52.2 ef	5,1
T4	Cassava minimum tillage	87.4 d	6.5	4.9 a	1,8
T5	Cassava 8 t ha^{-1} chicken manure	36.1 a	15.2	59.6 f	15,7
T6	Cassava 4 t ha^{-1} chicken manure (V)	59.3 abc	11.9	33.9 cde	12,5
T7	Cassava + Chamaecrista rotundifolia	78.0 cd	9.9	14.8 abc	10,3
T8	Cassava rotation	83.9 d	4.5	10.1 ab	3,7
T9	Cassava intensive tillage	43.2 ab	12.6	50.7 def	13,2

[1] Means followed by the same letter in column in 2001 are not significantly different at $p \leq 0.05$, Tukey's–test.

Soil structural degradation and consequently reduced water infiltration as found in the cropping systems of Santander de Quilichao were attributed to the application of chicken manure (T2, T5, and T6) and destructive soil use such as bare fallow or cassava monoculture treatments (T1 and T3). Beneficial effects of chicken manure on soil fertility were neutralized due to the higher amounts of manure. The application time had a remarkably great impact on superficial soil structure. The favorable growth conditions during rainy seasons on one hand alternated with periods of severe physical restrictions for plant development due to soil crusting and sealing on the other hand. Although final infiltration was comparably high in T5, the risk of higher surface run-off was increased due to extremely high rain events and high rain energies reported for this region. Superficial soil crusts are known to cause a decrease in infiltration. The crusts act as natural barriers against local water infiltration. Thus, as a consequence of long-term manuring, all chicken manure treatments were characterized by a strong decrease in final infiltration.

Conclusions: Due to the overall degradation of soil structure and soil aggregation, an intensification of organic manuring and intensive tillage practices leads to higher soil crusting and consequently lower infiltration especially in fragile landscapes such as the Andean hillsides. Hence, recommendations to farmers should include the research findings that conservative management practices like minimum tillage or crop rotations are highly adapted because the development of soil crusting and sealing is reduced, the soil physical and chemical status is improved, and infiltration is maintained.

Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with charcoal additions to soil

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Numerous soils from the tropics show presence of particles of black carbon originated as residues from periodic fires. In nutrient limited soils, charcoal additions have shown a positive impact on several soil quality parameters and on plant yields. The best documented case is the black Amazonian earths, anthopogenic soils that maintain their high productivity after centuries of use. Black carbon (C) has been identified as a key component in these soils. However, N availability was found to be lower on the black C rich Amazonian Dark Earths than adjacent soils. This N limitation in black C-rich soils was not found for legumes, and nodulation as well as occurrence of nodulating plants were significantly greater in forests on Amazonian Dark Earths than adjacent soils. Legumes also performed better on N-limited soils than grasses after charcoal applications (Rondon et al. unpubl. data). These results suggested that biological N fixation (BNF) is enhanced by charcoal. Possible explanation for this include: reduced availability of N due to immobilization associated with the high C/N ratio; higher pH and availability of other nutrients such as P; higher mycorrizal infection promoted by charcoal additions. There is a lack of studies relating BNF with black carbon and this research was consequently aimed at assessing the effect of increasing charcoal additions on nitrogen fixation by common beans using ^{15}N isotope dilution technique.

A greenhouse study was established using acid low fertility clay-loam Typic Haplustox from Colombian Savannas (Matazul farm). Before filling the pots, the air dried soil received a basal dose of fertilizer at rates equivalent to 300 kg ha^{-1} of lime, 20 kg P ha^{-1}, and 20 kg N ha^{-1} to enable proper growth of common beans. Four replicated pots per treatment were filled with 2 kilograms of soil and finely ground charcoal was mixed with the soil in four rates: 0, 30, 60 and 90 g charcoal kg^{-1} of soil. The applied charcoal was produced from logs of *Eucaliptus deglupta* under controlled conditions (350ºC during one hour) at the fuels laboratory from National University in Bogota. The pots were arranged in a completely randomized design. A common bean advanced line (BAT477) having good N-fixing characteristics and a non nodulating isoline (BAT 477NN) were planted after being inoculated with the appropriate Rhizobium strain (CIAT 899). Plants were allowed to grow for 75 days until pod filling. Moisture was maintained in the pots between 50-60% field capacity. Five days after germination, a solution of ^{15}N labeled ammonium sulfate (AS) containing 10% at ^{15}N was applied at a dose of 0.026 g AS. pot^{-1}. At harvest, plants were carefully removed from the soil, washed and separated into leaves + stems, roots and pods. Dry biomass was determined and then a finely ground subsample was used to reconstitute a composite plant sample for analysis of various nutrients, determined by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES). Another subsample was used for analysis of total N and ^{15}N content by Isotope ratio Mass Spectrometry.

As can be seen in Table 14, soil pH is increased by increasing the additions of charcoal as well as the cation exchange capacity of the soils. This resulted in a net increase in the availability of some soil nutrients such as potassium which increased linearly from around 100 $mg.kg^{-1}$ up to 490 $mg.kg^{-1}$ with the higher additions of charcoal. Magnesium also increased from 25 to 85 $mg.kg^{-1}$. Nitrogen clearly limited plant performance as indicated by the low plant biomass in the non nodulating plants. Likely as a result of higher pH and higher availability of some soil nutrients, total plant biomass, nitrogen uptake and yield also increased with low to medium additions of charcoal. Increments up to 40% were possible by the addition of 60 g of charcoal kg^{-1} soil. Nevertheless, the highest dose of charcoal did not have an effect on plant biomass of fixing beans and had a negative effect on biomass and total N uptake of the non nodulating bean isoline. The reason for a drop in BNF as well as biomass production (though not yield) at high charcoal application rates is not clear but may be related to nutrient unbalances, low N availability due to adsorption phenomena on the charcoal surface, and consequently low photosynthate production.

Table 14. Effect of increasing charcoal additions to a low fertility soil, on some soil properties and total biomass and nitrogen uptake by nodulating and non nodulating common beans.

Genotype	Charcoal dose ($g.kg\ soil^{-1}$)	Soil pH	CEC ($mmol_c\ kg^{-1}$)	Total plant biomass ($g.pot^{-1}$)	Total plant N uptake ($mg.\ pot^{-1}$)
BAT 477	0	5.04 e	108.2 a	4.40 a	82.65 a
	30	5.08 de	118.5 ab	5.59 b	97.13 ab
	60	5.24 c	131.7 b	6.12 b	107.81 b
	90	5.41 b	131.5 b	4.63 a	74.49 a
BAT477NN	0	5.13 cde	102.5 a	3.43 c	39.66
	30	5.17 cd	103.4 a	3.79 c	46.54
	60	5.34 bc	117.0 ab	3.78 c	39.70
	90	5.62 a	129.0 b	2.64 d	33.96

In Figure 14, values obtained for the proportion of total nitrogen derived from Biological nitrogen fixation are presented, as well as the partitioning of plant nitrogen from the soil and from the atmosphere. Nitrogen fixation was increased significantly with additions of charcoal, from around 50% in the soil alone to 72% with the highest dose. Most of the increase is reached with even low doses of charcoal.

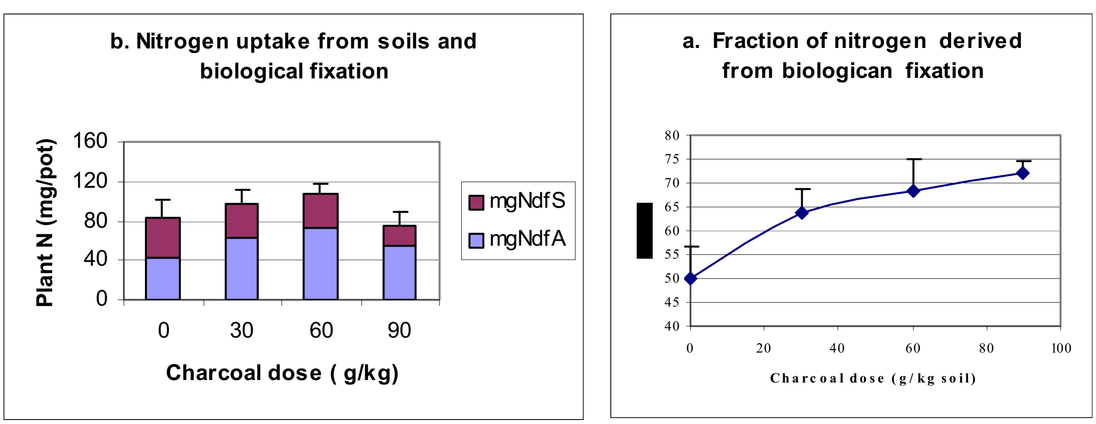

Figure 14. (a) Effect of increasing doses of charcoal addition on the proportion of nitrogen derived from BNF (%NdfA) and (b) plant nitrogen derived from soil (NdfS) and from biological fixation (NdfA) by plants of common beans.

This process could be associated with increased levels of both Molybdenum and Boron in the soils that received charcoal. Nitrogen total uptake from soils decreased with increasing charcoal doses. These results demonstrate the potential for increasing the N input by BNF into agroecosystems in highly weathered and acid soils by using charcoal applications. Future studies should include field experimentation to optimize BNF and explore the sustainability of BNF improvement by charcoal.

Stability, persistence and effectiveness of *Brachiaria humidicola* root exudates in inhibiting nitrification in soil

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This year, we have improved further the protocols in processing and testing of root exudates to determine the inhibitory effect on nitrification in soil (IP-5 Annual Report, 2003). We have tested the stability, persistence and effectiveness of the inhibitory effect from root exudates of *B. humidicola* on nitrification in soil. NI activity of 10 AT units g^{-1} soil (Soil from Tsukuba, Japan) was added to the soil with 182 ppm of N as $(NH_4)_2SO_4$ and incubated at 20 °C and 95% RH. Sequential sampling was done at 25 d intervals and the incubation was continued for 100 days. NI activity of 10 AT units g^{-1} soil was very effective in inhibiting nitrate formation in soil (about 70% inhibition) and remained effective in inhibiting nitrification (about 50%) until 75 days. A substantial portion of the inhibitory effect from NI activity was lost between 75 and 100 days of incubation in soil.

The synthetic nitrification inhibitor, ©Nitrapyrin did not inhibit nitrification effectively (only about 20% inhibition on nitrate formation) at 4.5 ppm under these conditions and lost its effectiveness after 30 days of incubation (Figure 15). Our results demonstrate that root exudates from *B.humidicola* are effective, persistent and sTable in inhibiting nitrification in soil (up to 75 days at least). Our results indicate that two *B. humidicola* plants of 60 to 70 d old can release up to 100 AT units of NI activity (in 24 h period) under optimum conditions. Our results also indicate that the NI activity release rates mentioned above can be maintained for long periods of time (we have tested up to 15 days and that the release rates were maintained).

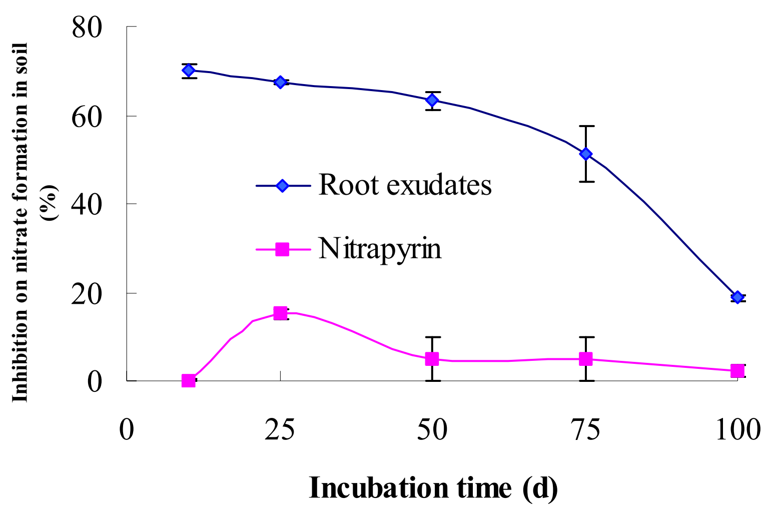

Figure 15. Inhibitory effect from root exudates (10 AT units NI activity g^{-1} soil) and nitrapyrin (4.5 ppm) on nitrate formation in soil during 100 d incubation period (Note: In control, nearly 90% of the added NH_4-N was nitrified by 75 days).

This is the first time that we have demonstrated the effectiveness, stability and persistence of root exudates (from *B. humidicola*) inhibitory effect on nitrification in soil.

Influence of NH_4-N on expression/regulation and release of NI activity in root exudates of *B. humidicola*

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We have tested the hypothesis that nitrogen forms (NH_4-N *vs* NO_3-N) can influence the release of NI activity from roots in *B.humidicola*. Plants of *B. humidicola* were grown hydroponically with two sources of nitrogen – 1 mM N as $(NH_4)_2SO_4$ or KNO_3 for 70 days. Root exudates were collected by keeping intact plant roots in distilled water, 1 mM NH_4Cl or 1 mM KNO_3 for 24 h. NI activity of root exudates was determined with the NI bioassay. Root exudates of NH_4-N grown plants showed NI activity, whereas NI activity was completely absent in the root exudates of NO_3-N grown plants (data not shown for NO_3-N grown plants as there was no NI activity detected in root exudates).

Presence of NH_4-N in the root exudates collection solutions further stimulated the release of NI activity in NH_4-N grown plants (Figure 16). The NI activity released in the presence of NH_4-N was several-fold higher than in the absence of NH_4-N (i.e. when root exudates are collected using distilled water).

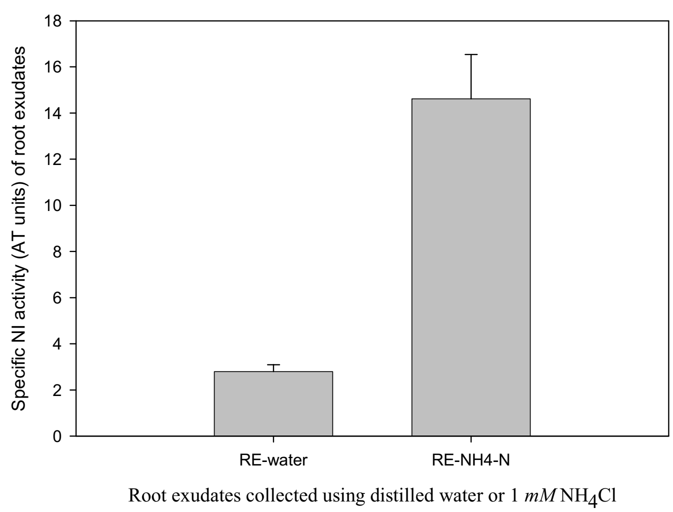

Figure 16. Influence of NH_4-N in the root exudates collection medium on the release of NI activity into root exudates from *B. humidicola* roots (Specific NI activity = NI activity g^{-1} root dry weight).

Our results support the hypothesis that presence of NH_4-N stimulates the synthesis and release of NI activity from roots (data not presented on the root tissue NI levels). The release of NI activity from roots appears to be a highly regulated phenomenon and NH_4-N in the rhizosphere is certainly one of the important regulating factors for the release of NI activity. Also, regulatory role of NH_4-N in the rhizosphere for the release of NI activity from roots further indicates the functional significance of NI activity in protecting NH_4-N in soil from nitrification.

Screening for genetic variability in the ability to inhibit nitrification in accessions of *B. humidicola*

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Collaborative research with JIRCAS, Japan, has shown that *B. humidicola* CIAT 679 inhibits nitrification of ammonium and reduces the emission of nitrous oxide into the atmosphere. Given these findings with the commercial cultivar of *B. humidicola* CIAT 679, and the fact that a range of inhibition of nitrification was observed among different tropical grasses, there is a need to determine the extent of genetic variation among the 69 accessions of *B. humidicola* that are part of CIAT germplasm bank. This information will be extremely useful to develop screening methods to select genetic recombinants of *Brachiaria* grasses that not only are resistant to major biotic and abiotic stress factors but also can protect the environment. Given the vast areas under *B. humidicola* in the tropics, reductions in net emissions of N_2O could also have important environmental implications.

The main objective was to quantify differences among 10 accessions of *B. humidicola* regarding the nitrification inhibition activity of root exudates collected from plants grown under greenhouse conditions using infertile acid soil. Also we intend to test the relationship between nitrification inhibition and root production in terms of biomass and length.

A sandy loam Oxisol from the Llanos (Matazul) of Colombia was used to grow the plants (4 kg of soil/pot) under greenhouse conditions. A basal level of nutrients were applied before planting (kg/ha): 40 N, 50 P, 100 K, 66 Ca, 28.5 Mg, 20 S and micronutrients at 2 Zn, 2 Cu, 0.1 B and 0.1 Mo. A total of ten accessions were used (accessions CIAT 679, 6133, 6369, 6707, 16866, 16867, 16886, 16888, 26149, 26159). A control without plants was also included. The experiment was arranged as a completely randomized block design with four replications. Each pot contained four plants. After sowing, plants were allowed to grow for 15 weeks and were cut to 10 cm height to simulate grazing effects under field conditions. Plant tissue was dried and saved.

Plants were allowed to re-grow during 5 weeks more to promote a well developed root system and then ammonium sulfate was applied in solution at a rate of 38.5 mg $N\text{-}NH_4$/kg soil (equivalent to 100 kg $N\text{-}NH_4$ per hectare). Five weeks later plants were harvested (at 25 weeks after sowing). At the end of the experiment, plants were carefully removed from soil minimizing mechanical damage to the roots. Soil adhered to the fine toots was removed and the roots were rinsed with deionized water. Once clean, the roots were fully immersed in 1 liter of deionized water and were allowed to produce root exudates during 24 hours. Collected root exudates were kept in the refrigerator and were reduced in volume to approximately 100 ml using a freeze drier.

Harvested plants were separated into shoot and roots. Root length was measured using a root length scanner. Dry matter content and N status of both shoot and root biomass was determined. At harvest time, soil samples were extracted with KCL and analyzed for nitrate and ammonium levels. The concentrated root exudates were further concentrated using a rotovapor using protocols that were developed for this purpose. The final concentrate was tested for its nitrification inhibitory activity using a specific bioassay developed at JIRCAS.

Results on dry matter partitioning among shoot and root biomass from the comparative evaluation of the ten accessions are presented in Table 15. No significant differences were found in total biomass production among most of the CIAT accessions except for the accessions of 16866 and 16867, which were lower than the rest of the accessions. However, significant differences among accessions were found in root biomass production. The commercial cultivar, CIAT 679, which has been used in most of the previous work, seems to have root biomass around the average value for the group tested. The accession 6707 produced the highest root biomass among the tested accessions. Values of root biomass of this accession were more than twofold greater than the value for the lowest in the group, the accession 26149.

Results from the bioassay indicated substantial level of NI (nitrification inhibitory) activity in the root exudates of most of the accessions tested (Table 16). However a range in NI activity was found among the tested accessions.

Table 15. Dry matter partitioning differences among ten accessions of B. *humidicola* grown in pots under greenhouse conditions. Plants were harvested at six months after planting.

CIAT Accession Number	Dry matter (g/pot)		
	Root biomass	Shoot biomass	Total biomass
CIAT 679	4.29 (1.19) a	14.76 (3.76) d	19.05 (3.68) f
CIAT 6133	4.14 (1.65) a	15.06 (1.90) d	19.20 (3.49) f
CIAT 6369	4.77 (1.58) b	14.35 (1.59) d	19.12 (2.52) f
CIAT 6707	4.92 (0.72) b	17.84 (2.75) d	22.75 (2.61) f
CIAT 16866	3.52 (0.89) a	13.45 (0.96) e	16.97 (0.95) g
CIAT 16867	3.50 (0.38) a	14.70 (1.65) e	18.20 (1.56) g
CIAT 16886	4.48 (1.09) b	15.53 (4.56) d	20.01 (5.12) f
CIAT 16888	3.26 (0.72) a	16.97 (1.40) d	20.22 (1.17) f
CIAT 26149	2.39 (0.30) c	17.31 (3.20) d	19.70 (3.09) f
CIAT 26159	2.96 (1.43) c	16.15 (2.09) d	19.10 (2.20) f

Numbers in parenthesis indicate standard deviation. In a given column, data followed by the same letter indicate non- significant differences (LSD, $p<0.05$).

Accessions could be grouped in 3 classes in relation to their specific NI activity. Group 1 with the accession CIAT 16867 showed no NI effects, behaving similarly to other grasses such as *Panicum maximum,* which also lack the NI activity. Group 2 that included accessions CIAT 6133, 6707, 16866, 26149, 6369, and 6707 showed similar levels of NI that was observed with the commercial cultivar CIAT 679. Group 3 that included the accessions 16886, 16888, and 26159 showed significantly higher levels of NI than the accession 679. The accession 16888 was outstanding in its NI activity with a value of more than three times to that of the value of CIAT 679.

Table 16. Nitrification inhibitory activity (total NI activity pot^{-1} and specific activity g^{-1} root dry weight) of the root exudates from ten accessions of *B. humidicola* grown under glasshouse conditions. Plants were grown for six months before the collection of root exudates.

CIAT Accession Number	NI activity (in AT units pot^{-1})	Specific NI activity (in AT units g root dwt^{-1}) 1
CIAT 679	68.84 (24.1) cd	7.48 (8.4) c
CIAT 6133	51.58 (16.9) cd	12.24 (2.83) c
CIAT 6369	86.94 (14.3) c	20.72 (4.2) c
CIAT 6707	69.68 (5.5) cd	14.86 (1.2) c
CIAT 16866	41.48 (6.9) d	11.26 (2.9) c
CIAT 16867	-48.55 (18.1) e *	-13.42 (3.35) d
CIAT 16886	128.05 (15.3) ab	27.95 (5.8) bc
CIAT 16888	160.95 (6.08) a	53.76 (17.45) a
CIAT 26149	33.5 (39.8) d	15.22 (18.15) c
CIAT 26159	126.17 (19.9) b	46.33 (19.0) ab

Note: Numbers in parenthesis indicate standard deviation. In a given column, data followed by the same letter indicate non-significant differences (LSD, $p<0.05$). NI activity is expressed as AT units; One AT unit is defined as the inhibitory activity caused by the addition of 0.44 µM of allylthiourea (AT) in the bioassay medium. Thus, the inhibitory activity of the test samples of root exudates is converted into AT units for the ease of expression in numerical form.

*Negative activity indicates that nitrification was stimulated by the root exudates.

Results on NI activity indicate that wide genetic variability exists among accessions of *B. humidicola* in relation to the effectiveness of root exudates to inhibit nitrification in soils. This genetic variability for NI activity could be exploited in a breeding program to select for genotypes with different levels of NI activity. Once all the accessions in the gene bank are tested, accessions with superior NI activity could be used as parents to regulate NI activity in the genetic recombinants together with other desirable agronomic traits.

The presence of substantially higher levels of NI activity in the root exudates of the two CIAT accessions (16888 and 26159) draws attention to the need to study these accessions in more detail. The immediate task is to continue the screening of other accessions of *B. humidicola* from the gene bank and to initiate screening of other commercially important grasses and crops for their ability to inhibit nitrification. As a continuation of this work, this year we have initiated the screening of another 11 accessions of *B. humidicola* including all materials that are classified as putatively sexual. An additional experiment will be conducted to obtain and test NI activity of root exudates from maize, rice, sorghum, soybean, cowpea and common bean. Results from this study will be reported next year. Further research work is needed to determine the relative importance of total NI activity *vs*. specific NI activity in influencing the nitrification process (i.e. inhibition) in a soil environment.

On-going Work

Dynamics of external mycelium development of three AMF species in symbiosis with *Melinis minutiflora* and its impact on water stable soil aggregation

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Earlier studies have shown that AMF fungal hyphae is fundamental in soil aggregation because greater hyphal lengths significantly favored a greater percentage of water stable aggregates. Our studies also indicate that host plant can lead to differences in soil aggregation potential with both native and a mixed inoculant AM fungi. Because different host plants may vary in their association with AM fungi and differentially contribute over time to soil aggregation processes, we need to study the temporal dynamics of external hyphae growth to further understand their function in soil. In order to get a better understanding of the relative capacity of hyphae from different AM fungi to aggregate and stabilize degraded soils in this study we compare the impact of three AMF species (*Entrophospora colombiana*, *Gigaspora margarita* and *Glomus manihotis*) hosted by *Melinis minutiflora* on the dynamics of external mycelium development and water sTable soil aggregation.

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

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Research conducted at JIRCAS and CIAT for the past three years using *B. humidicola* has shown that root exudates from this tropical grass have the capability to inhibit/suppress the nitrifying populations in the soil. Factors such as presence of NH_4-N in the soil seem to have a stimulating effect on the expression of nitrification inhibition (NI) activity in the root exudates of *B. humidicola*. Differences have been found among accessions of *B. humidicola* with regard to their NI activity. Also, our recent studies involving soils incubated with root exudates of *B. humidicola* and soybean have shown that root exudates from *B. humidicola* have suppressed the N_2O emissions and inhibited the nitrification process, while those of soybean seem to stimulate the nitrification process in soils. Soybean (usually in rotation with maize) is becoming increasingly important as a crop not only in Latin America but also in many tropical and temperate regions. Other grasses such as *Panicum maximum* lack the NI activity, while the *Brachiaria* hybrid cv. Mulato was found to have a moderate level of NI activity. The use of this hybrid is expanding rapidly in Latin America due to its high productivity and forage quality.

All these above studies were conducted either using hydroponic systems or soil in pots under greenhouse conditions to test and verify the concept of the biological phenomenon of nitrification inhibition. There is a clear need to validate some of these findings under field conditions. This year a collaborative (CIAT-JIRCAS) long-term experiment was initiated to validate the phenomenon of NI under field conditions and to monitor whether the NI activity is a cumulative process in the soil.

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 fertilizer N use efficiency, reduce nitrate pollution of surface and ground waters as well as reduce net impact on the atmosphere through reduced emissions of nitrous oxide, could have potential global implications for sustainable agricultural development and environmental protection.

The field experiment was established on 31 August 2004 at CIAT-Palmira on a Mollisol (Typic Pellustert) as a randomized complete block (RCB) design with six treatments and 3 replications. Annual rainfall at this site is about 1000 mm with a mean temperature of 25 ^{o}C. Soil is fertile with a pH of 6.9. Two accessions of *B. humidicola* were included: the reference material (CIAT 679) that has been used for most of our previous studies, and the high NI activity germplasm accession (CIAT 16888). The Hybrid Mulato was included as a moderate NI and *Panicum maximum* var. common was included as a negative non-inhibiting control. A crop rotation (maize-soybean) was included to assess under field condition the recent finding that Soybean lacks NI ability (indeed accelerate nitrification), while maize shows some degree of inhibitory capability. As first crop of the rotation we used maize variety (ICA V109). A plot without plants where emerging weeds are removed manually is used as an absolute control.

Plot size for each treatment was 10m x 10m. Irrigation will be provided if necessary. Maize was planted from seeds and the tropical forage grasses were propagated from vegetative cuttings. Fertilizer will be applied (broadcast) for every crop cycle, consisting of (kg/ha) 96 N (as urea), 48 K, 16 P, 0.4 Zn, 0.4 B and 8 S. The fertilizer is split into two equal applications: one at 20 days after sowing of each crop (either maize or soybean) and the other at flowering time at approximately 60 days after sowing.

A number of soil and plant parameters will be measured at every four months. These include nitrate and ammonium availability in the soil, dynamics of nitrifier organisms in soil, plant nitrogen uptake and nitrous oxide (N_2O) emissions. The NI activity of soil water extracts will be measured using the bioassay. Soils samples will be periodically collected and sent to JIRCAS to assess changes in inhibitory compounds in the soil. Gas samples for measuring N_2O fluxes will be collected every month. Once a year, soil incubation studies will be conducted using rhizosphere soil, to monitor nitrogen dynamics and fluxes of N_2O. Currently plants are growing well and the initial sampling is expected in January 2005. Results from this field study will be reported next year.

Use of APSIM to simulate rotations of maize and bean with inputs of chicken manure and soluble phosphate fertilizer in Tropical Hillsides of Colombia

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Crop production on Andosols in the tropics is limited primarily by availability of phosphorus (P). The high allophane contents of these volcanic ash soils strongly sorb phosphates. To maximize P fertilizer use efficiency it is necessary to quantify the residual value of previous P fertilizer applications.

The APSIM model (Agricultural Production Systems Simulator; www.apsim.info) simulates the effects of management or nutrient availability on soil quality and crop growth. Recently a phosphorus capability has been added to APSIM. This study extends the testing of the P capability to a wider range of soils and crops. APSIM can be used for farming systems where both organic and inorganic sources of nutrients are supplied. In this study, two experiments were carried out to evaluate APSIM for rotations of maize and beans, responding to different rates of chicken manure and soluble phosphate fertilizer applied as annual inputs or residual effects from an initial application.

The experiments were established on farm in Pescador, Cauca, Colombia (2°48'N, 76°33'W, 1500 m.a.s.l.). The area has a mean temperature of 19.3°C and 1900 mm of annual rainfall. Soils are derived from volcanic ash depositions and classified as Oxic Dystropepts, with a bulk density close to 0.8 $Mg.m^{-3}$, pH-$_{H2O}$ 5.1, total C > 52 g kg^{-1}, effective CEC of 6.0 $cmol_c$ kg^{-1} and P availability (BrayII) of < 11 mg kg^{-1}.

Residual Phosphorus Response experiment (RPRE) and chicken manure experiment (CHME) were established as random complete block designs with four replications. RPRE consisted of nine levels of P (as triple superphosphate) while CHME had four levels of chicken manure (local organic fertilizer) (Table 17). Experiments started with planting of maize (*Zea mays* L. cv Cresemillas) in September 2001. Bean (*Phaseolus vulgaris* L. cv ICA Caucayá) was planted in March 2002. The rotation of maize and bean crops was continued through two more cycles. Basal nutrients (N, K, Ca, Mg, and micronutrients) were applied to all treatments in RPRE but not in CHME.

To predict the response to P and chicken manure additions in both experiments, daily temperature, radiation and rainfall were generated using Marksim. Soil characteristics (i.e., nutrient contents, P fractions, plant available water content) were measured in the field at the start of the experiments. Crop parameters (i.e., time to flowering, time to maturity and nutrient concentrations) were measured and used as inputs for the model. For practical purposes, only the first two cycles of maize and bean are reported For which measured yield data were available.

Table 17. Phosphorus and chicken manure amounts applied annually to maize in a maize-bean rotation in Pescador, Cauca, Colombia.

	Annual application rate (kg ha^{-1})			
Treatments	**2001**	**2002**	**2003**	**2004**
RPRE[1*]				
P0	0	0	0	0
P5A	5	5	5	5
P10A	10	10	10	10
P10R	20	0	0	0
P20R	20	20	20	20
P40R	40	0	0	0
P40A	40	40	40	40
P80R	80	0	0	0
P160R	160	0	0	0
CHME[2]**				
CH0	0	0	0	0
CH3	3	3	3	3
CH6	6	6	6	6
CH12	12	12	12	12

[1] Annual application of P (kg ha^{-1}) to maize as triple superphosphate, [2] Annual application of Chicken manure (t ha^{-1}) to maize. * A= annual, R= residual, ** Nutrient content of chicken manure varied from year to year; average values were 37% C, 3.3% N, 1.5% P, 2.0 K, 3.8% Ca, 0.9 % Mg.

Measured data: For RPRE in the first cycle the highest yields of biomass and grain were obtained at the highest rates of P application (P160R and P80R) (Figure 17). In the second cycle however, yields for P80R declined but P40A increased relative to P160R. For CHME, yields of biomass and grain increased with application rate of chicken manure in both cropping cycles (Figure 18). Bean shoot biomass and yield in the second cycle, particularly in RPRE, was very low because plants were severely affected by diseases caused by *Rhizoctonia solani* and *Colletotricum lindemuthianum*.

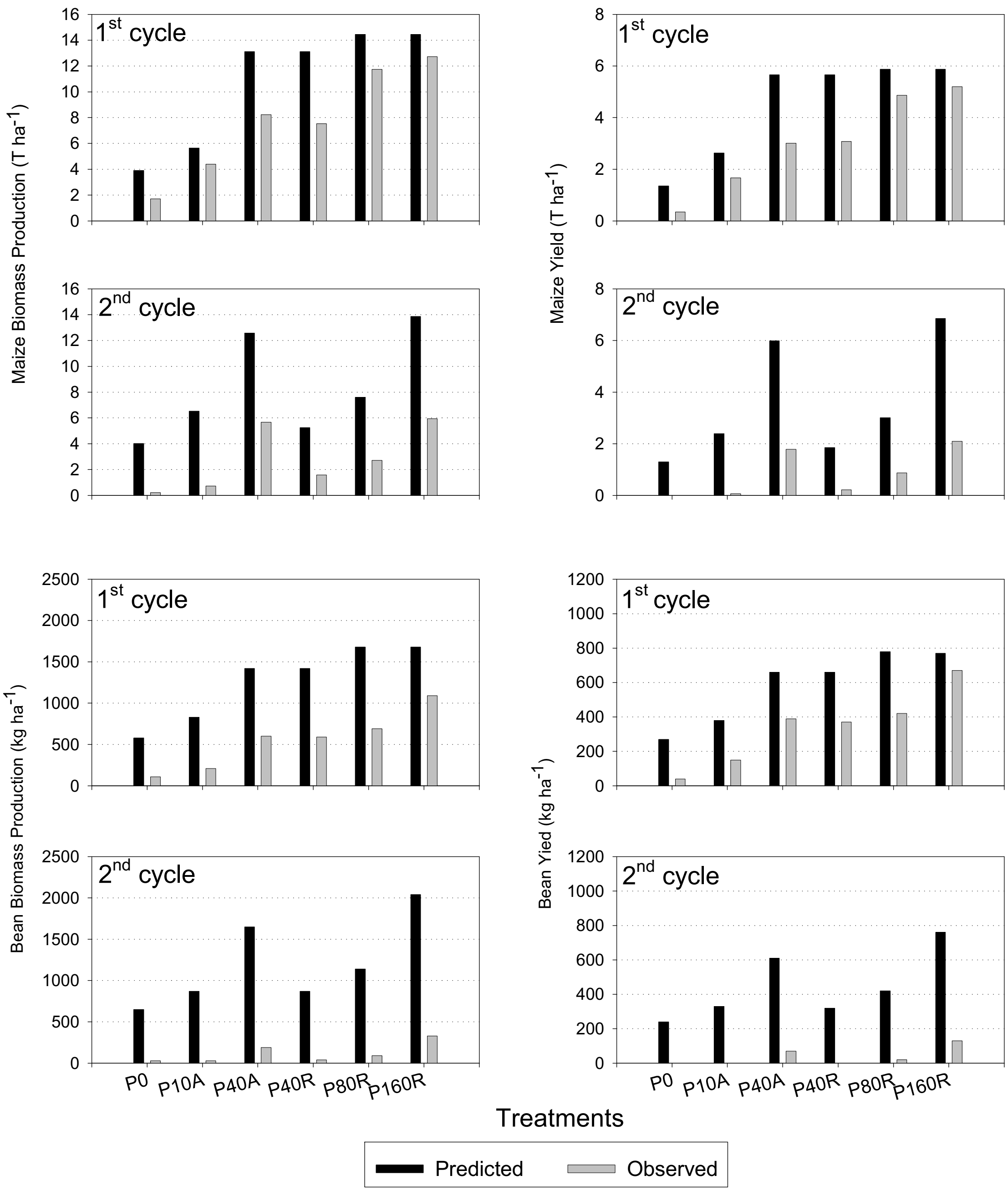

Figure 17. Predicted and observed yields of shoot biomass and grainfor maize/bean rotation with different applications of triple superphosphate in Pescador, Colombia.

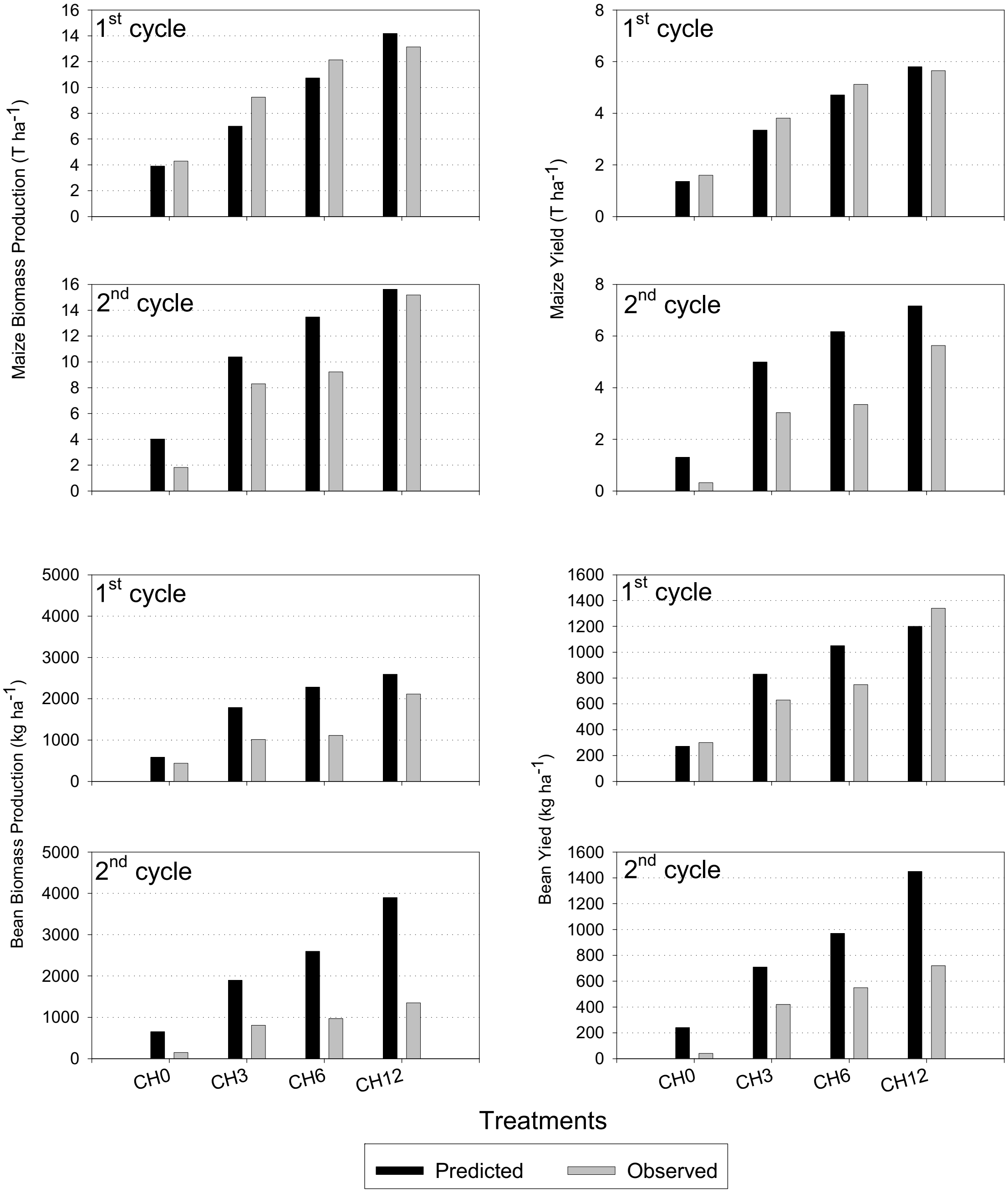

Figure 18. Predicted and observed yields of shoot biomass and grain for maize/bean rotation with different rates of chicken manure (CHME) in Pescador, Colombia.

In the first cropping cycle, yields obtained with the higher rates of superphosphate (P80R and P160R) or chicken manure (6 and 12 tha^{-1}) were similar, but for the lower rates of application yields declined markedly in the second season.

The results suggest that the P inputs in RPRE are inadequate to maintain sustainable yields or there is some other limiting factor that is being corrected by chicken manure additions.

Simulated data: There are numerous reasons why the model might fail to adequately predict the observed pattern of response. These include: 1) insufficient crop parameterization because maize and bean varieties used were not adequately characterized. This was the first ever attempt to model a P response for beans using APSIM; 2) generated data from MarkSim apparently overestimated total rainfall for 2001 and 2002 when compared with meteorological data measured at the site. This results in APSIM predicting that the site is very wet with leaching of nitrate N from the root zone (data not shown); and 3) APSIM does not consider pest and disease problems, which clearly affected bean yields for the second cropping cycle in RPRE.

Nonetheless there was a fair degree of conformity between the predictions and the observed data. For the maize crops, the highest yields obtained at the high rate of chicken manure and the response to the lower rates were predicted reasonably well by the model. For RPRE, the model tended to overpredict the effectiveness of the P40 treatments in the first cycle and the residual effects of the initial P treatments in the second cycle.

The agreement is sufficiently encouraging to undertake further measurements to better specify the crop parameters for the cultivars grown and to revisit the simulations when crop yield data for the third cycle become available. Opportunities also exist to evaluate model performance in terms of soil P status (i.e., compare soil P test data with model predictions of the labile P pool).

1.2. Impact of within-farm and within landscape soil fertility gradients on the functioning of the most relevant soil based processes understood

TSBFI-Africa

Published Work

Optimizing Soil Fertility Gradients in the Enset Systems of the Ethiopian Highlands: Trade-offs and Local Innovations

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In: Bationo, A., Kimetu, J. and Kihara, J., 2004. Improving human Welfare and Environmental Conservation by Empowering farmers to Combat Soil Fertility Degradation, Yaounde', Cameroon, may 17-21, 2004.

Enset ventricosum is a perennial, security crop that feeds about 13 million people in Ethiopia. It is grown in the homesteads, covering about 18% of the farm, in mixture with Coffee, kale, and other vegeTables. The recent shift from enset to cereals and continual soil fertility decline in the outfields caused food deficit for at least 3 months in a year. The objective of this work was to evaluate the effect of soil fertility gradients on enset growth, identify the major growth limiting nutrients, and identify farmers' decision making criteria in allocating resources to various enterprises. The research was conducted on farmers fields of resource rich (G1) and poor (G3) for four years (2001-2004). Enset transplants were planted in homestead and outfields. Application of fertilizers by farmers to different units over seasons and years was recorded. Enset growth and nutrient content was measured. The results showed that the G1 group produced about 2xs more organic waste than G3, and purchased chemical fertilizers 5xs more than the G3 farmers. About 80 % of the organic resource produced was allocated for maintaining soil fertility, while 20% being allocated as cooking fuel. Of this 65% is allocated for the enset field in the homestead. There was significantly higher N, P, K and Ca contents in the home stead soils than in the outfield, regardless of farmers' resource endowment. The P content of the outfield was the lowest, less than 25% of the P content of the homestead. Similarly organic matter in the outfield was only about 40% of the homestead. Enset plants grown in the outfields experienced about 90% height reduction and 50% reduction in pseudo stem diameter, regardless of resource categories, while the NPK content of the plant tissues grown in the outfield was significantly higher, in some case up to 150% than those planted in homestead. We thus

concluded that growth reduction in the outfield was not directly related to NPK deficiency, but it could have been caused by off-season moisture stress in the outfields, manifested by low soil organic matter. The attempt to attract resources to the outfield using enset as an attractant crop failed, not because of labour shortage but because of unavailability of enough organic resources in the system. Hence on spot management of nutrients was initiated by farmers.

Completed Work

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

P. Tittonell, B. Vanlauwe, P. A. Leffelaar, K. D. Shepherd and K. E. Giller
National Agricultural Research Organisation, Kampala, Uganda; Kenya Agricultural Research Institute, Nairobi, Kenya; Kenyatta University, Nairobi, Kenya; Egerton University, Nakuru, Kenya; Makerere University, Kampala, Uganda; Katholieke Universiteit Leuven, Leuven, Belgium; Wageningen University, Wageningen, The Netherlands.

Strong gradients of decreasing soil fertility are found with increasing distance from the homestead in tropical farming systems, due to differential resource allocation within the farm. Nutrient use efficiency varies strongly along these gradients of soil fertility in African smallholder farms. Targeting soil-improving technologies to the more degraded soils as a means for restoration of agricultural productivity is often unsuccessful. The existence of soil fertility gradients within smallholder farms must be considered when designing integrated soil fertility management strategies, aiming at an improved efficiency for the overall nutrient dynamics within the farm system. 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 for farm management assessment, participatory resource flow mapping, 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. Within-farm heterogeneity was classified by defining field types, considering distance from the homestead and differences in resource allocation, and according to farmers' perceptions. Management practices, crop productivity, nutrient balances and soil fertility status were documented for different field types and farmers' land classes within the farms. Both field typologies were in agreement, as farmers classified the home fields commonly as 'fertile'. Despite strong differences across sub-locations, input use, food production, C and N balances and general soil fertility status varied between field types, though not always correspondingly. Concentration of nutrients in the home fields was verified for the average extracTable P levels and secondarily for exchangeable K, whereas the spatial heterogeneity in soil C and N contents were only important at individual farm scale. Farmers managed their fields according to their perceived land quality, varying the timing and intensity of management practices along soil fertility gradients. The internal heterogeneity in resource allocation varied also between farms of different social classes, according to their objectives and factor constraints. The interaction of these with the sub-location-specific, socio-economic and biophysical factors, had important implications for farming system characterisation necessary to facilitate targeting research and development interventions to address the problem of poor soil fertility.

On-going Work

Quantification of the range of within-farm soil fertility gradients and identify the major biophysical and socio-economic factors driving their generation

A Muriuki and B. Vanlauwe
TSBF Institute of CIAT

That declining soil fertility and resultant land degradation are the causes of the ever decreasing agricultural production in East Africa is now widely acknowledged. The need to rectify the problem is pertinent if the region is to become self sufficient in food production. Crops grown on depleted soils typically respond to N and P fertilizers, but fertilizer recommendations, where they exist, cover large areas and ignore within-farm soil fertility gradients, which have become a common feature of smallholder farms. The Farm Gradients Project (FG) reported here is attempting to develop site-specific recommendations for Integrated Soil Fertility Management (ISFM) based on local soil fertility classification schemes. It is hypothesized that within-farm soil fertility gradients are large enough to be taken into account when planning the allocation of scarce nutrient inputs at the farm level.

The project characterized 240 smallholder farms located in 3 benchmark sites in East Africa namely in Vihiga and Siaya districts in western Kenya, in Tororo and Mbale districts in eastern Uganda and in Meru South and Mbeere districts in central Kenya. Farm selection involved characterization of benchmark sites using secondary data, superimposition of GIS layers for soils, agro-ecological zones and administrative boundaries, and random selection of 4 sub-locations (Kenya) or parishes (Uganda). In the final stage, a 'Y' sampling frame was used to select 10 farms in each sub location/ parish. The 'Y' frame was considered to be most efficient for quantifying spatial correlation between sampling units and for removing spatial correlation effects when investigating factors affecting soil fertility status.

Seven forms were prepared to capture the administrative, biophysical and socio-economic characteristics of each farm. Administrative information was used to identify each farm from country to the village level. Socioeconomic information included a farm map, information on the household head, the farm's labor structure, inputs used, off farm income, food security, livestock, and links to nearby markets while biophysical information was collected on a field by field basis and included field characteristics e.g. slope, landscape position, flooding, erosion, hard-setting, rock/stone cover etc and management information e.g. fallow, nutrient input use, conservation, farmer soil fertility assessment etc. Soil samples were taken to 50 cm soil depth, from a 5m by 5m quadrant placed at random locations within each field and the auger holes geo-referenced. The field corners were also geo-referenced. The samples were analyzed for diffuse reflectance spectra (0.35 to 2.5 μm). A corresponding soil fertility index (SFI) was assigned and used to estimate corresponding soil organic carbon (SOC) and extracTable P values. A database was been set up and efforts to transfer all the data from hard copy to electronic form are well advanced.

Preliminary analyses of the SOC and organic P variance structures (Table 18) using a mixed model approach, confirm the existence of large soil fertility variation at all levels, but particularly within farms. The variation increased, district < sub-location < farm < within farm for SOC and sub-location < district < farm < within farm for extractable P. These results show that soil management recommendations made at the district or higher levels will not allow farmers to manage this variability adequately. Field covariates such as distance from the homestead, number of years cultivated, number of seasons that fields have been fallowed etc. were used to explain this variability. Position on the landscape and distance from the homestead significantly contributed to the variability of SOC and extracTable P values (Table 19).

Table 18: Overall variance structure for (SOC) and extracTable P in East African smallholder farms

Random term	SOC		ExtracTable P	
	Variance	**Percent of total variation**	**Variance**	**Percent of total variation**
District	3.58	9.5	8.13	18.0
Sub location	5.41	14.3	4.43	9.8
Farm	7.36	19.5	12.57	27.8
Within farm	21.43	56.7	20.16	44.5
Overall mean (mg kg^{-1})	20.4	-	10.4	-
Within farm range (mg kg^{-1})	20.4 $\pm$ 9.3	-	10.4 $\pm$ 9.0	-

Table 19: Significance of covariates in overall variance structure of soil organic C (SOC) and available Olsen-P.

Covariate	SOC (p values)	Olsen P (p values)
Distance from homestead	<0.001	<0.001
Seasons of fallow	0.002	0.864
Farm size	0.710	0.545
Presence/absence of flooding	0.724	0.319
Years of cultivation	0.110	0.010
Land use	0.086	0.808
Position on landscape	<0.001	<0.001

When covariates such as position on the landscape, land use and distance from the homestead were used simultaneously in the model (Table 19), their inclusion did not change the previous variance structure (Table 18) considerably. Position on the landscape and land use are commonly used when making agro-ecological zone based fertilizer recommendations while distance from the homestead has been observed to influence fertility in smallholder African holdings. Evidently, identifying the major contributors to this variability at the global (regional) scale is not easy. Exploration at lower scales could yield more meaningful results, thus data analyses will be initiated at these scales.

Table 20: Effects of position on landscape, land use and distance from homestead in the overall variance structure for SOC and ExtracTable P

Random term	SOC		ExtracTable P	
	Variance	Percent	Variance	Percent
District	3.52	10.0	12.61	26.2
Sub location	4.35	12.4	2.23	4.6
Farm	7.28	20.7	12.57	26.1
Field	20.03	56.9	20.66	43.0

The project also explored whether farmers were aware of the existence of soil fertility gradients in their farms. They were asked to rate the fertility of fields into three classes: low, medium and high, and their responses compared to measured values of SOC and extracTable P in soil samples taken from those fields. Farmer perceptions were fairly agreeable with measured values. For example, of the 510 fields rated low, 378 had low SOC and low extracTable P, 110 had low SOC but medium values of extracTable P, while 22 had low SOC and high values of extractable P (Table 20). Fields rated low but with medium SOC values and low P were 113, while those which had low extractable P but high SOC values were 19. Of the 716 fields rated medium, 514 corresponded to medium values of extracTable P and SOC. Farmers rated 333 fields as having high soil fertility and of these, 222 had high measured values of extracTable P and SOC. Clearly, farmers can identify fields with differing fertility levels fairly accurately. In the coming year, two MSc studies will be carried out to explore farmer knowledge of local soil quality indicators.

As a follow up to the farm characterization work, two field experiments were laid out in April 2004 in 2 sub-locations per district in 5 districts (Vihiga, Siaya, Meru South, Mbale, Tororo). The first experiment aims at diagnosing the most limiting nutrients among N, P, K, and S for maize production while the second will determine specific site responses to N and P fertilizer for a maize/bean intercrop (Table 21).

Table 21: Farmers' assessment of the soil fertility status versus measured values of SOC and extractable Within-farm soil fertility gradients on soil-based processes underlying ISFM practices P.

		Extractable P (number of fields)			
	Farmer rating:	Low	Medium	High	Grand total
Organic C (number of fields)	Low	378	110	22	510
	Medium	113	514	89	716
	High	19	92	222	333
	Grand Total	510	716	333	1559

Sub-locations were selected on the basis of widest variation of SOC and most contrasting mean SOC. As far as possible, the experiments were laid out in farms that had been previously characterized by this project. Where new farms were included, preparations are underway to characterize them following the Farm Gradients Project protocol. All new farms are located within the Y in affected districts. Each experiment was laid out in 5 randomly selected farms per sub-location and within each farm, in two fields following a paired plot design. The selected fields represent the extremes of soil fertility status for potential cereal fields, one field having the highest SOC value, the other the lowest. Potential cereal fields located in the bottomland and drainage positions on the landscape were automatically disqualified as were homestead fields, fields under perennial crops and those under fallow. Treatment layout in both experiments was completely randomized.

Table 22: Treatment structure of the limiting nutrient and site-specific response trials.

LIMITING NUTRIENT TRIAL (all data below in kg/ha)					**SITE-SPECIFIC RESPONSE TRIAL (all data below in kg/ha)**				
Treatment	N	P	K	S	Treatment	N	P	K	S
1	0	0	0	0	1	0	0	0	0
2	80	60	60	24	2	80	60	60	24
3	80	60	60	24	3	0	22	0	0
4	80	60	60	0	4	20	22	0	0
5	80	60	0	24	5	40	22	0	0
6	80	0	60	24	6	80	22	0	0
7	0	60	60	24	7	80	0	0	0
					8	80	40	0	0
					9	80	60	0	0

The experiments will continue throughout 2004. Data from the Limiting Nutrients trial (Table 22) will be used to determine the relative importance of missing nutrients, the potential yield of maize under NPKS application and under inherent nutrient supply, as well as to estimate the recovery fractions of applied nutrients using the QUEFTS model. The output from the Specific Site Response trial will be a sub-location based yield response curve to N and P application.

Influence of spatial farm variability on Soil Organic Matter and Nitrogen dynamics in Farmer Field School generated Practices
Peter Ebanyat, Rob Delve, Mateete Bekunda

The broad objective of this Ph.D. research is to increase understanding and enhance use of ISFM practices by targeted application taking into account within and between smallholder farm variability in soil characteristics. The specific objectives to be researched are:

- To understand the impacts of long-term farm management practices on creation and/or reinforcement of within-farm soil fertility gradients
- To understand the need for targeted ISFM practices within-farms
- To evaluate the impact of targeted ISFM practices on ecological and socio-economic sustainability at farm scale
- To develop guidelines for implementation of targeted ISFM practices taking into account existing soil fertility gradients

In the first year the focus has been on classing the 10 farms in each of three villages and understanding their systems in terms of nutrient balances, mean partial balances across the villages for N, P and K are shown in Figure 19 (a). N balances were most negative for Keria village (-2.3 kg ha^{-1}). Both P and K balances at village level were positive although there were variations at farm level in each of the villages of Onamudian (b), Chelekura (c) and Keria (d). Mineral fertilizer is hardly used in farms across the villages. Equally, the use of organic manures is very low. Grazing and atmospheric deposition contribute a substantial inflow of nutrients to farms at the village level. The greatest losses of N occur through leaching while for P and K from manure dropped outside (Table 23).

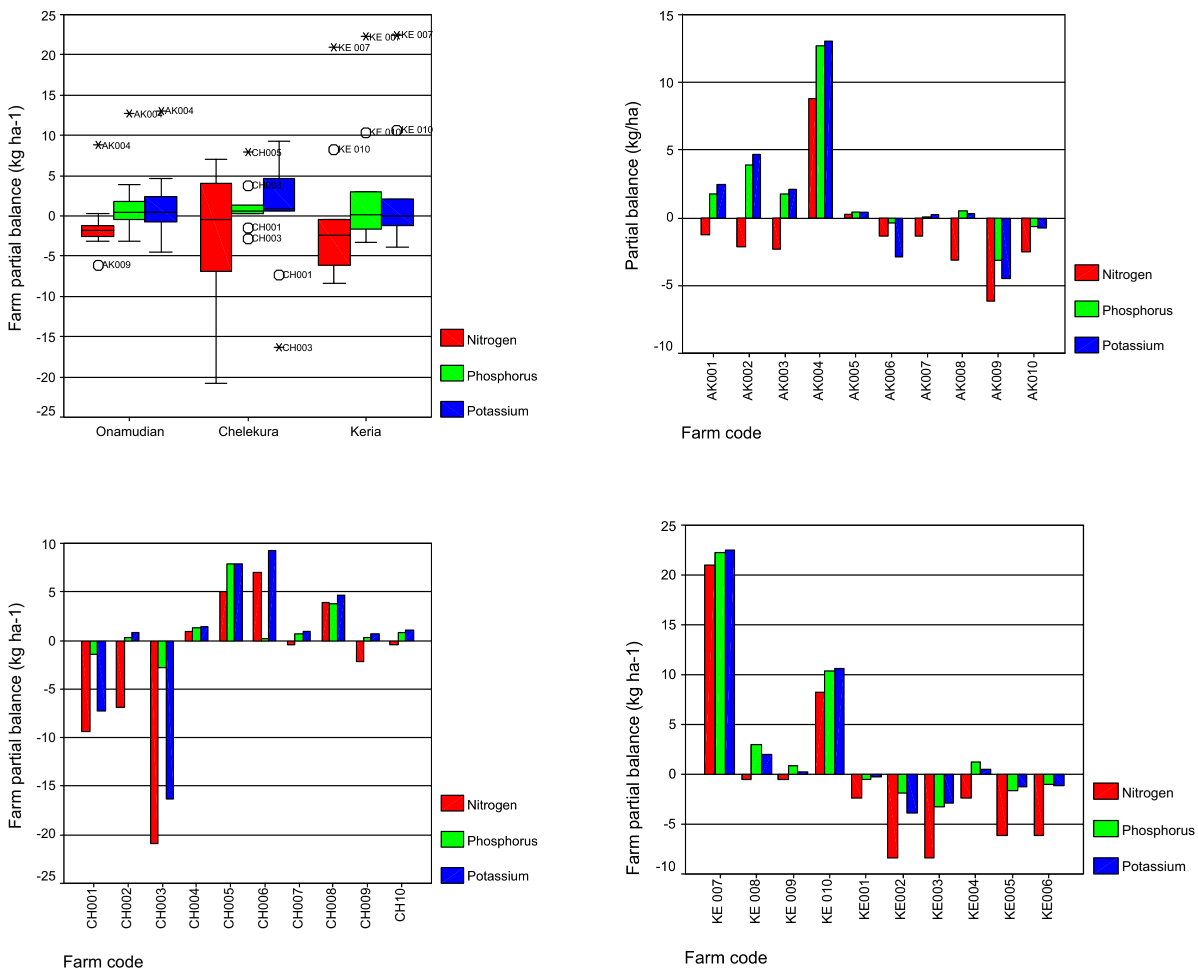


Figure 19. Mean partial nutrient balances by village (a), and farm level in the villages of Onamudian (b), Chelekura (c) and Keria (d)

Table 23. Major nutrient flows in the at village scale (kg ha^{-1}).

	Village								
	Onamudian			**Chelekura**			**Keria**		
Flow	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
In. Fert.	0.0 (0)	0.0(0.0)	0.0 (0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0(0.0)	0.0 (0.0)	0.0 (0.0)
Manure	0.7 (1.4)	0.1 (0.2)	0.2 (0.3)	3.4 (9.4)	0.8 (2.2)	2.4 (6.8)	0.1 (0.2)	0.0(0.0)	0.0 (0.0)
Grazing	6.7 (7.1)	6.7 (7.1)	6.7 (7.1)	3.6(4.3)	3.6(4.3)	3.6 (4.3)	7.4(12.0)	7.4(12.0)	7.4(12.0)
Atm. Dep.	4.5 (0)	0.7 (0.0)	2.9 (0)	4.5(0.0)	0.7 (0.0	2.9 (0.0)	4.6 (0.3)	0.8 (0.0)	3.0 (0.2)
BNF	1.8 (1.6)	0.0 (0.0)	0.0 (0)	2.0(2.6)	0.0 (0.0)	0.0 (0.0)	1.0 (1.1)	0 (0.0)	0.0 (0.0)
Crop prod	- 0.6 (0.7)	-0.2(0.2)	-0.2(0.3)	-2.2(4.6)	-0.5(0.7)	-1.9(4.8)	-1.3(1.7)	-0.3 (0.3)	-0.8 (0.9)
Crop resid	0.0 (0)	0 (0.0)	0.0(0.0)	-1.0 (2.3)	-0.3(0.6)	-0.3(0.7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Manure	-4.0(0)	-3.8(3.7)	-4.4(4.0)	-2.1(2.2)	-1.5(1.7)	-2.2(2.4)	-3.3(5.0)	- 3.3 (5)	-3.3 (5)
Leaching	-13.6(3.7)	0.0(0.0)	-0.6(0.5)	-11.2(5.3)	-0.1(0.2)	-0.9(0.7)	-10.9 (8)	0.0 (0.0)	- 0.8(0.5)
Gas Loss	-3.2 (8.1)	0.0(0.0)	0.0 (0)	-2.4(1.2)	-0.1(0.2)	0.0 (0.0)	-2.3(1.3)	0.0 (0.0)	0.0 (0.0)
Erosion	-0.8 (0.6)	-0.4(0.3)	-1.2(0.9)	-1.1(1.3)	-0.8(0.5)	-1.9(1.4)	-0.7(0.9)	-0.4 (0.3)	-1.1(1.0)
Hum Excr	-4.0 (2.9)	-1.2(0.9)	-0.8(0.6)	-4.0 (5.2)	-1.0(1.3)	-1.3(2.6)	-3.4(1.9)	-0.9 (0.5)	-0.7 (0.4)

Values in brackets are standard deviations

A selection criteria for the farms, in terms of socio-economic and biophysical characteristics was then used to develop a farm typology through Principal Cluster Analysis (Figure 20)

Farm classification

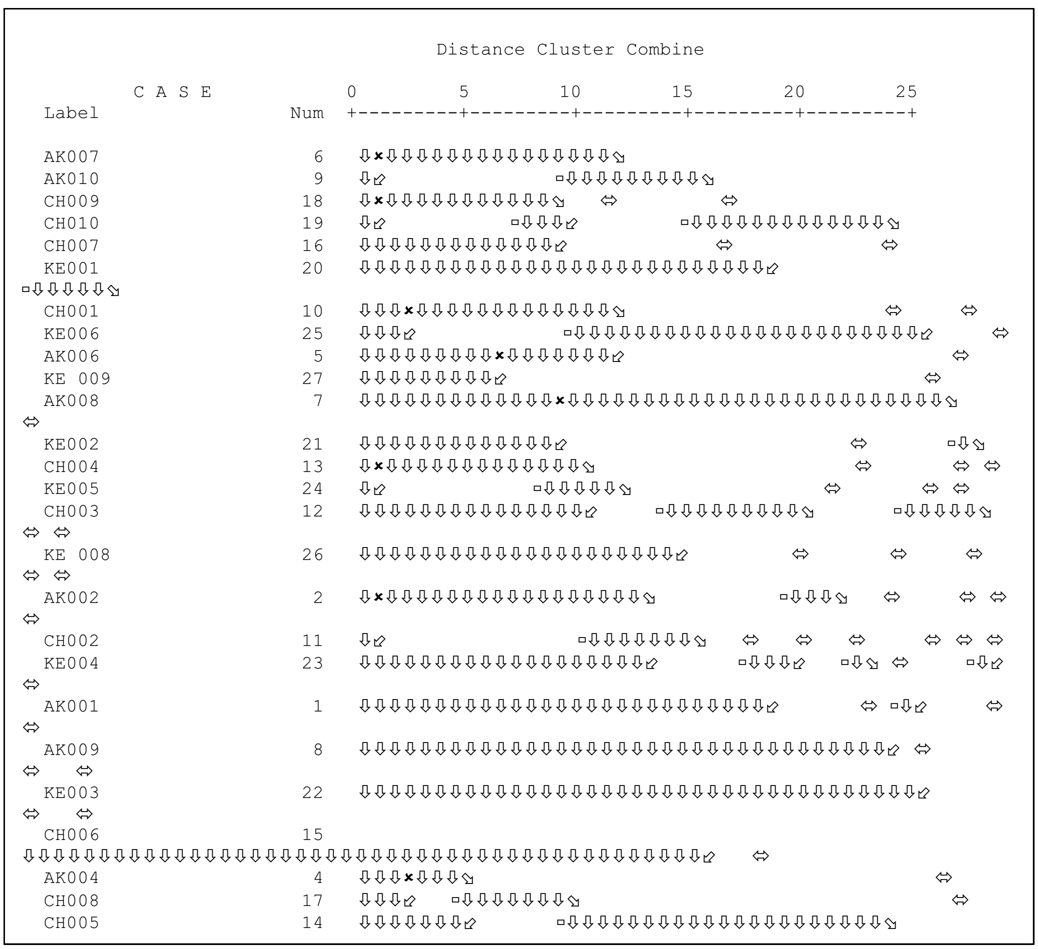


Figure 20. Average linkage dendrogram of farm data using the ochai coefficient

Data collected using the NUTMON tool were used in agglomerative cluster analysis using SPSS after Z score standardization. (Di)similarity of farms was derived using the using the Ochai coefficient (van Tongeren, 2002) leading to the generation of the dendrogram (Figure 20) above. Cutting off point from cluster distance of 22.5 will yield three clusters. Two farms were excluded in the analysis because there peculiarity that tended to cluster 28 in one class and each of them into different classes. The major highly correlated variables i.e. total farm area, net farm incomes, family earnings, total livestock units and total capital were selected to define three farm classes which are inclined wealth status (Table 24).

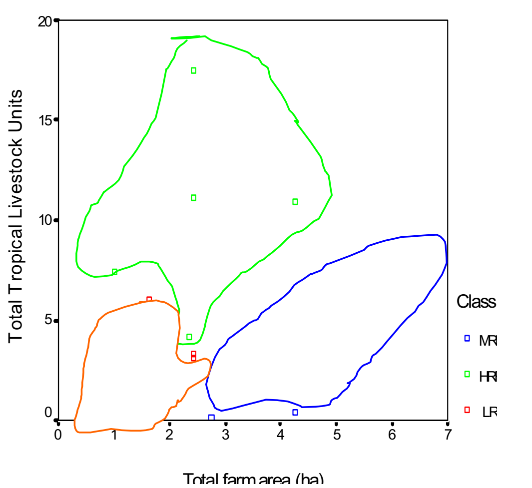
The HRF are very few but have the highest total tropical livestock units and net farm incomes (Figure 21 a & b). Although total farm area is an important variable it does not well differentiate the farm classes because the MRF rather than HRF have largest farm sizes (Figure 22). Across the farm classes renting out of land is negligible but the LRF rent-in some land.

Farm nutrient balances were less negative for N and positive for P and K in the HRF farms followed by the MRF and is mainly driven by grazing input from TLU (Table 24)

Table 24: Characteristics of farm classes

Variable	Farm class		
	LRF	**HRF**	**MRF**
	(n=13)	(n= 5)	(n= 10)
Total farm area (ha)	1.26 (0.41-2.43)	2.49 (1-4.25)	4.05 (2.75-6.32)
Tropical Livestock Units	2.03 (0-6.00)	10.22 (4.2- 17.50)	3.01 (0.1-7.40)
Total capital (Ush)	928,542 (295,540 - 2,066,680)	3,066,222 (1,815,676 - 3,983,676)	2,070,868 (936,694 - 4,579,676)
Net farm Income (Ush/yr)	100,253 (-243,099 – 638,724)	442,605 (-11,100 – 995,899)	216,807 (1,799 – 479,000
Family earning (Ush/yr)	134,201 (-142,100 – 778,724)	725,605 (99,467 – 1,608,760)	254,447 (1,800 – 490,066)
Off farm income (ush/yr)	33,947 (0 - 150,000)	283,000 (0 - 900,000)	40,639 (0 -160,000)

(Values in brackets are minimum -maximum)



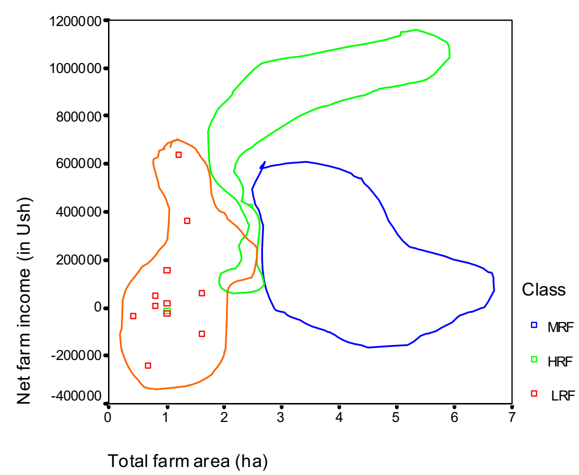


Figure 21. Farm clusters as determined by plots of (a) total tropical livestock units and total farm area and (b) net farm incomes and total farm area.

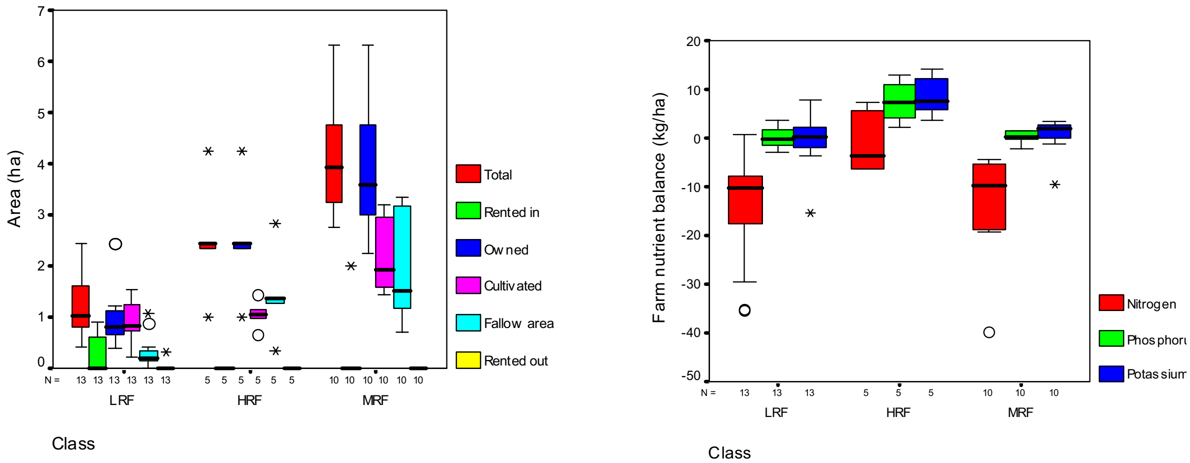


Figure 22. Total farm sizes and (a) land utilization and (b) farm nutrient balances by farm class.

In the 2004b season representative soil samples were be taken from all fields (following Y sampling procedure) of selected 10 farms in each village, data collection from all fields is necessary because the studies aim at expressing gradients at farm scale. In this area, average number of fields is 10. Infields, mid and out fields will likely be defined in relation to distance. Soil analysis data (200 samples from both villages taken at depth of 0-20 cm) of the fields will be used for selection of fields for experimental studies based on the main soil variable influencing the gradients within farms. This studies aim at obtaining gradient at farm scale through simple aggregation. Soil samples will be sampled using the same methodology as other Soil fertility Gradient (SFG) projects n TSBF and Near Infra-red Spectroscopy will be used for analysis soils, and data added to the SFG database. During 2005 ISFM options selected for testing by farmers will be evaluated.

Activity 1.3 Improved understanding of the relationship between agricultural intensification and the abundance, diversity and function of tropical soil biota

TSBFI-Africa

On-going work

Standard method for land use inventory and classification (including land use intensity) for adoption in the BGBD project defined

J.J. Ramisch, J. Huising, P. Okoth, CSM-BGBD partners

At the annual meeting of the CSM-BGBD project, held in Embu, Kenya, it was agreed that the country teams would apply a minimum set of standard questions for conducting their baseline surveys of socio-economics, land-use history, current practices and awareness of BGBD in their sites. This set of topics would, at a minimum, include background information on the respondent (i.e.: the land users responsible for the sites at which each of the BGBD inventory sampling activities was taking place + respondents from the broader community to establish how representative the BGBD sample sites were of the surrounding practices), the respondent's land holdings, current land management practices, and land-use history, and finally the current awareness of the respondent of below-ground organisms or processes. Since the project is expected to have greatest impact on awareness and understanding, it was felt that the most important element of the baseline was the "pre-contact" perceptions of respondents of below-ground organisms, such as whether or where their influences were strongest or weakest, or whether impacts of these organisms were largely beneficial, negative, or neutral as far as local priority crops or other land use activities were concerned.

The standard set of methods was developed and circulated in mid-2004. However, it is not clear to what extent this set has actually been incorporated into the actual baselines conducted within the teams, as the expected inter-team communication and sharing of both survey instruments and preliminary results has not taken place. Repeated efforts at stimulating such interactions using the project listserve and direct e-mailing have not been successful. The greatest exchanges so far have been from direct, personal interaction, which typically only involves one country team at a time, usually during field visits by the project coordination.

TSBFI-Latin America

Published Work

A global assessment of mycorrhizal colonization of *Tithonia diversifolia*

R. A. Sharrock[1], F. L. Sinclair[1], C. Gliddon[2] , I. M. Rao[3], E. Barrios[3], P. J. Mustonen[4], P. Smithson[5] D. L. Jones[1] and D. L. Godbold[1]
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Mycorrhiza 14: 103-109 (2004)
Tithonia diversifolia (mexican sunflower), is a shrub commonly used as a green manure crop in Central and South America, Asia and Africa, as it accumulates high levels of phosphorus and other nutrients, even in depleted soils. In root samples collected from the global distribution of *Tithonia* we examined the degree of mycorrhizal colonisation and estimated the families of associated arbuscular mycorrhizal (AM) fungi. No colonization by ectomycorrhizas was found. The degree of colonisation by AM fungi was on average 40%, but ranged between 0 and 80%. No mycorrhizal colonisation was found in the samples collected from the Philippines or in one each of the Rwandan and Venezuelan samples. Throughout its global distribution (Costa Rica, Nicaragua, Indonesia, Honduras, Mexico, Kenya and Rwanda), *Tithonia* forms mainly associations with *Glomaceae.* Only in one location in Nicaragua were associations with other families (*Acaulosporaceae*) found.

On-going Work

The Effects of the Quesungual Agroforestry System of Western Honduras on Soil Macrofauna and Soil Quality

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Soil contains one of the most diverse assemblages of organisms of any habitat on earth and still soil biota remains largely unexplored. Although soil biota performs crucial ecological functions in natural and agricultural ecosystems, the relationships between soil macrofauna diversity, soil characteristics and land-use are poorly understood, as are the mechanisms that govern these interactions. To date, little attention has been paid to the potential of agroecosystems to conserve and manage biological diversity within soil. Because soil macrofauna can have positive influences on soil fertility due to the effects of their activities on soil physical, chemical and biological properties, agricultural practices that promote diversity and abundance of soil macrofauna may actually promote improvements in soil quality and productivity in a positive feedback cycle. In marginal farming environments, such an increase in soil quality could have

important ramifications for food security, income and quality of life. The overall objective of this study is to determine the effects of the Quesungual agroforestry system on the diversity, distribution and abundance of soil macrofauna and the implications for soil quality.

The Quesungual agroforestry system presents a prime opportunity for studying the relationships and feedback mechanisms among land use, soil characteristics and plant biodiversity and soil macrofauna, and for examining whether this system can benefit both farmers and biodiversity conservation. This research project will concentrate on relationships between soil quality and the Quesungual system, focusing on the diversity, abundance and ecological functions of soil macrofauna as a component and indicator of soil quality. The exploration of spatial and temporal hetereogeneity in soil properties and soil fauna communities relative to patterns of vegetation and land usewill be part of this study.

There is growing recognition that the integration of local knowledge and scientific knowledge can lead to insights into sustainable management and reduce risks associated with farming difficult environments such as hillsides. There has been relatively little research into farmers' perceptions, values and observations of soil macrofauna diversity and community composition, although some traditional farmers in areas of the tropics are known to regard the presence of particular species, such as earthworms, as indicators of soil fertility. This study will examine farmers' perceptions of soil biodiversity, and investigate whether soil macrofauna is, or could be, used as an indicator of soil fertility.

Activity 1.4 Development of an integrated approach to soil fertility and pest management (ISFPM)

TSBFI-Africa

Published Work

Nitrogen contributions of cowpea and groundnut to soil nitrogen, N fertiliser recovery and nematode infections in legume-sorghum rotations in the Guinean zone of West Africa

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The effects of cowpea (*Vigna unguculata*) and groundnut (*Arachis hypogea*) on succeeding sorghum were studied during three years (2000 to 2002) in a weakly acid Ultisol of the agronomic research station of Farakô-Ba (4^{o} 20' West, 11^{o} 6' North and 405 m altitude), located in the Guinean zone of Burkina Faso. Two field agronomic experiments were used. The first experiment was a factorial design in a split plot arrangement with four replications using crop rotations as first factor and fertilizers as second factor. Biological nitrogen fixation (BNF), legume effects on succeeding sorghum yields, N recovery and nematode infections were measured. In the second experiment, Nitrogen Fertiliser Equivalencies (NFE) of groundnut and cowpea were studied. In the first year (2000), a simple randomised block experiment with four treatments (groundnut-sorghum, cowpea-sorghum, maize-sorghum and sorghum-sorghum) and four replications was used. During the next year (2001), sorghum was sown on all plots and each main plot was split into five subplots and five rates of N fertiliser (0, 20, 40, 60 and 80 kg N ha^{-1}) appliedsubplots. Then, the experiment became a factorial 4 x 5 design in a split plot arrangement with four replications. The results show that compared to continuous cultivation of sorghum, cowpea and groundnut increased succeeding sorghum yields. Cowpea was the most efficient in increasing the yield of the succeeding sorghum. Legume-Sorghum rotations increased sorghum grain yields by 60 to 300 % compared to continuous sorghum. The N fertiliser equivalency of groundnut (35 kg N ha^{-1}) was higher than that of cowpea (25 kg N ha^{-1}), indicating that using these legumes like precedent crop may involve an economy of 25 to 35 kg N ha^{-1} in mineral fertilisers. Groundnut fixed 8 to 23 kg N ha^{-1} and the percentage of N derived from the atmosphere varied from 27 to 34 %. Cowpea fixed 50 to 115 kg N ha^{-1}

and the percentage of N derived from the atmosphere varied from 52 to 56 %. Compared to the mineral NPK fertilizer alone, legumes fixed more nitrogen from the atmosphere when phosphate rock (PR), dolomite or manure was applied with mineral fertilizers. Compared to continuous sorghum, Legume-Sorghum rotations increased soil mineral nitrogen. The soils of Legume-Sorghum rotations provided more N than those of continuous cultivation of sorghum. A better use of N fertiliser was also observed in legume-sorghum rotations. In continuous sorghum, fertiliser N use efficiency (NUE) was 20%. But in Cowpea-Sorghum and Groundnut-Sorghum rotations, NUEs were 28 and 37% respectively and the highest total N uptake by sorghum was observed in legume-sorghum rotations. Compared to continuous sorghum, groundnut-sorghum rotations decreased soil and sorghum infection by nematodes while cowpea-sorghum rotations increased nematode infections.

TSBFI-Latin America

On-going Work

Integrated Soil Fertility/Pest and Disease Management approaches to address root-rot problems in common beans

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[4]*Universidad del Valle, Cali, Colombia.*

Consensus about societal demands for agricultural sustainability and biodiversity conservation has been reached in the past decade (UNCED-1992). New approaches to continuing problems, like soil degradation and soil pest and diseases, are then needed in order to achieve agricultural sustainability. Our overall working hypothesis in this study is that combining soil fertility and pest management approaches would provide a unique opportunity to exploit synergies allowing a better control of soil fertility/pest&disease limitations to crop productivity than either approach alone.

The management of organic matter is crucial to the activities of the soil biota. Use of green manures can have a multi-faceted beneficial effect on crop productivity arising from (i) protection of the soil from erosion; (ii) increased nutrient cycling; (iii) synchronized nutrient release and uptake by the plants; and (iv) increase in soil biological activity and diversity of microorganisms, which in turn can lead to minimized damage and loss from soil borne pathogens, and increased activity of beneficial microorganisms. However, different sources of green manure can have different effects on the balance between populations of harmful and beneficial organisms because they have different rates of decomposition and nutrient release as well as different impact on soil moisture and temperature that invariably affects relative population sizes. For this reason, we considered important to evaluate the effect of different sources of green manure on three key functional groups of soil biota: 1) pathogens, 2) microregulators and 3) microsymbionts. We are studying the population dynamics of soil pathogenic fungi (*Fusarium, Sclerotium, Macrophomina, Rhizoctonia* and *Pythium*), soil nematodes (discriminated by feeding habit), soil microsymbionts (mycorrhiza, rhizobia) during cultivation of common bean in soils infested with pathogenic fungi. Evaluations were carried out by: a) directly identifying and quantifying different soil biota from functional groups mentioned above and by quantifying growth of external hyphae as a measure of AMF activity and b) indirectly, by evaluating the incidence of disease on susceptible plant genotypes and by plant infection test for determining the native rhizobia symbiotic potential. The relative position of these three groups in the soil food web suggests the potential for soil organic matter management to reduce soil pathogenic fungi populations and incidence in bean plants by change induced in soil moisture and temperature, nutrient availability and interaction with other soil organisms.

An experiment was established in CIAT's Santander de Quilichao Research Station, using a plot that has a history of high incidence of root rot pathogens. The plots were planted with a root rot susceptible bean variety A 70. Immediately after planting, the plots were covered with three green manures treatments: (1) rapidly decomposing *Tithonia diversifolia*(TTH); (2) intermediate rate of decomposition (but greater soil cover due to leaf morphology) by *Cratylia argentea*(CRA); (3) slow decomposing (*Calliandra calothyrsus* (CAL) at a rate of 6 ton ha^{-1}; and (4) control (no green manure added). The experiment was replicated five times. Soil samples (0-10 cm) collected during the cropping season included at least planting and harvesting time. Samples were collected within rows and between rows, to measure the effect of the rhizosphere of bean plants on the soil biota studied.

Diversity of soil pathogenic fungi: Preliminary data revealed that plots receving CRA had a significantly less fungal diversity ($p<0.05$) than plots receiving the other sources of green manure or the control (Figure 23). No significant differences were observed between the other treatments and the control. However, since this is the second season after initiation of the experiment, it is still too early to make sound conclusions.

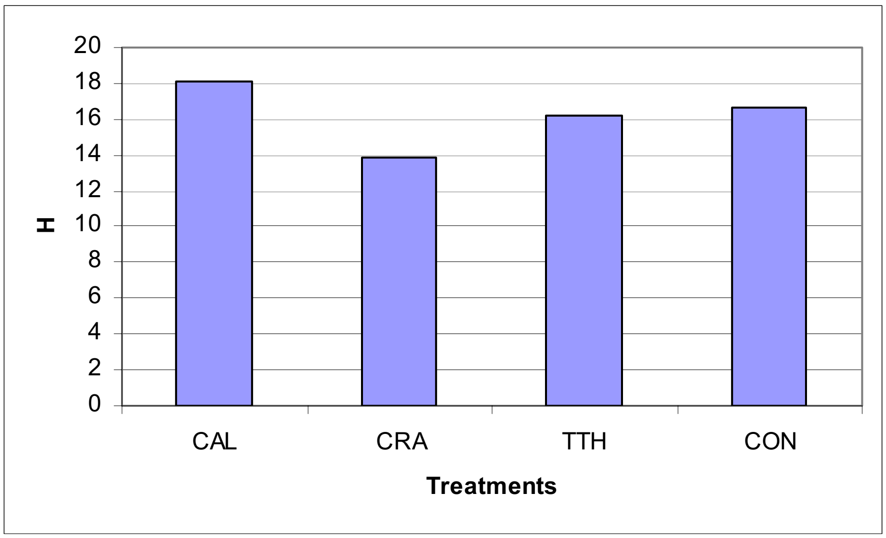

Figure 23. Diversity of soil-borne fungi in plots receiving or not receiving different sources of green manure. H represents the Shannon Wiener diversity index.

The most frequently isolated fungus was *Aspergillus* (A) in all treatments, while Macrophomina (Ma) and Rhizoctonia (R) were the least isolated fungi (Figure 24). Other fungi that were isolated included *Fusarium* (F), *Penicillium* (P), *Humicola* (H) and *Mucor* (M). The presence of *Penicillium* is interesting, as some species of this fungus are known to solubilize phosphorus. *Humicola* is a fungus that has been found to be involved in decomposing organic matter, and this was found in abundance in plots receiving *Calliandra*. Several fungi were isolated that are currently being classified. These were tentatively placed under the "unknown" group (D). It is possible that some of these fungi could be potential biological control agents. Although *Macrophomina* has been observed in the past in high frequencies and incidence on infected plants, this fungus was not detected in the soil samples analyzed thus far. It is possible that the method of analysis that is used leads to the exclusion of this fungus, or the high incidences observed under field conditions results from seed-borne inoculum.

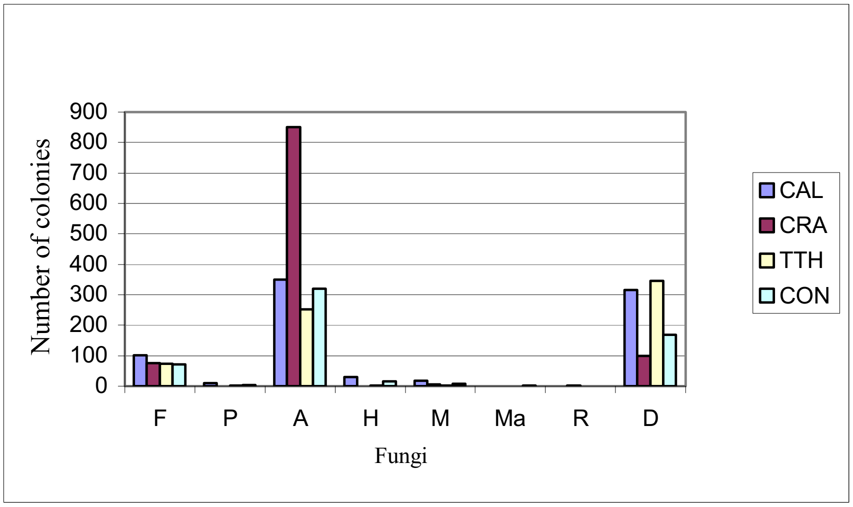

Figure 24. Frequency of different fungi isolated from plots receiving none (control) or a fast, intermediate and slow decomposing green manure or the control.

Abundance of soil nematodes: Total number of soil nematodes was always higher in the row than between the rows highlighting the importance of the bean plant rhizosphere effect (Figure 25). On average greater number of nematodes were found when *Tithonia* was applied to the soil and the overall order was TTH>CRA>CON=CAL . Taxonomic identification of nematodes and classification into feeding groups is on going and should help in the interpretation of abundance trends observed.

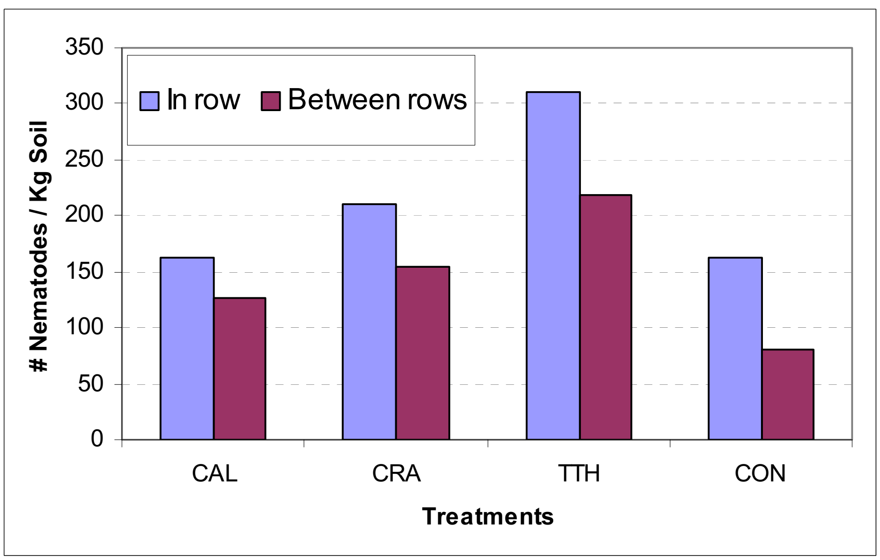

Figure 25. Total number of nematodes from plots receiving a fast, intermediate and slow decomposing green manure or the control

Incidence of root rot pathogens: Significant differences were observed in the incidence of root rots in some treatments when compared to the control (Figure 26). Application of *Calliandra*, and *Tithonia* significantly reduced disease incidence ($p<0.05$), while a slight increase in disease incidence was observed in plots receiving *Cratylia.* Analysis of the samples collected from these plots revealed that most of the root rot symptoms were caused by *Macrophomina phaseolina* and *Fusarium solani*, while *Rhizoctonia solani* was occasionally isolated. Significant yield increases were observed for plots treated with *Calliandra* (10%) and reduction for plots receiving Tithonia (-29%) (Figure 26). Although a slight increase in yield was observed (1.2%) for plots receiving *Cratylia*, this was not significantly different from the control plots.

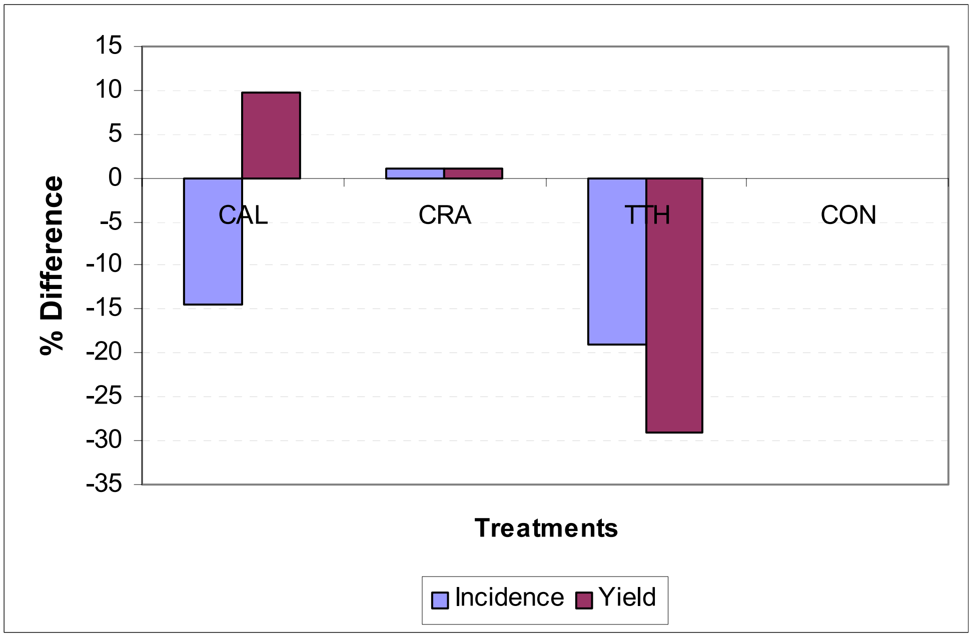

Figure 26. Incidence of root rots and yield of the bean genotype A 70, grown in plots with or without different types of green manures expressed as a percent of control treatment.

First results indicate that despite the relatively limited time of green manure treatments some initial trends can be identified. Compared with the control application of *Calliandra* resulted in increased bean yield, reduced incidence of root rots and low nematode abundance. In the case of *Cratylia*, there were minor differences in root rot incidence, yield and nematode abundance (in row) when compared to the control. Although disease incidence was low in plots receiving *Tithonia*, bean yield was also negatively affected. Taxonomic identification of nematodes would help to understand if high nematode populations in TTH were involved in reducing bean yield. In addition, the impact of treatments on the bean plant symbiosis with mycorrhiza and rhizobia needs to be included for a more complete explanation of yield differences encountered. Nevertheless, yield differences were likely also influenced by a combination of physico-chemical factors including differences in nutrient release by the three green manure sources.

While at this early stage application of *Calliandra* seems to offer the best results we need to examine how transient or cumulative these effects are and the mechanisms of action involved. The potential exists that unknown beneficial microorganisms are promoted in the soil by green manures and thus can potentially be used to manage root rot pathogens and/or for promoting plant growth. We are currently evaluating fungi that have tentatively been grouped under the “Unknown” group for potential antagonistic effects, as well as *Penicillium* species for their ability to solubilize phosphorus.

Assessing the effects of Bt Crops and Insecticides on Arbuscular Mycorrhizal Fungi and Plant Residue Carbon

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The world market for transgenic crops is expected to be US$ 8 billion by 2005, increasing to US$ 25 billion by 2010. This new technology has been most rapidly deployed in industrialized countries, but the proportion of transgenic crops grown in developing nations has increased steadily each year, from 14% in 1997 to 24% in 2000. The global area planted with these crops increased more than 25-fold between 1996 and 2000, to about 44 million ha, with plants engineered to express Cry insecticidal proteins from the bacterium *Bacillus thuringiensis* (Bt) representing about 25% of these crops. Estimates indicate that Bt technology products could save farmers about US$ 2.7 billion of the US$ 8 billion or so spent annually on insecticides worldwide.

The enormous progress made in developing and disseminating insect-resistant Bt crop varieties is exciting from the perspective of increasing productivity, but worldwide public opinion is still very reserved regarding the acceptability of Bt crops. The greatest constraint appears to be the uncertain risks to environmental and human health posed by these crops compared to the insecticides normally used to contain pest damage. This study addresses the lack of knowledge concerning the potential environmental impact of Bt technology vs. insecticides on non-target organisms and soil biology, biochemistry and ecology. There have been few assessments to determine if Bt crops pose any risk to the abundance and diversity of detritivore soil arthropods and microorganisms in the soil. Further, it is not known whether potential variations in the dynamics of carbon (C) allocation and in-field rates of residue decomposition between transgenic and non-transgenic plants will alter C turnover and/or sequestration in soil.

Recent results suggests that a number of Bt crops exhibit slower residue decomposition rates than their non-Bt counterparts; however, this research is being conducted with finely chopped residue under controlled laboratory conditions, and is not directly applicable to the field. It is important to know if rates of Bt and non-Bt residue decomposition do indeed vary consistently during multiple years of field trials, and to determine if observed differences are a result of inherent changes in the engineered plant or Bt toxin-mediated effects on soil organisms such as the arthropods that initiate residue degradation in soil. If the decomposition rate of Bt and non-Bt crops does differ, and Bt crops use significantly less insecticide than their non-Bt isolines, then the potential for decreasing greenhouse warming potential (GWP) through increased C sequestration in soil by the slower-degrading Bt residues and decreased CO_2 and carbon monoxide emissions through reduced use of insecticides should be assessed.

The objective of this project is to determine the effect of Bt corn (US), cotton (Colombia), and rice (China) on soil organisms, with an emphasis on the symbiotic association between plant roots and arbuscular mycorrhizal (AM) fungi and on soil arthropods important in the primary decomposition of crop residues. We will also compare the rates of decomposition and the fate of Bt vs. non-Bt residue C and evaluate the potential for increasing C sequestration in soil using Bt crops. The crops have been chosen so that we can evaluate effects on soil organisms under both aerobic and anaerobic conditions:

Activity 1.5 Improved understanding of scaling–up and out processes for improving soil health and fertility

TSBFI-Africa

Published Work

Estimating yields of tropical maize genotypes from non-destructive, on-farm plant morphological measurements

P Tittonell, B Vanlauwe, PA Leffelaar and KE Giller

Agriculture, Ecosystems and Environment, 2004, In Press

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 cob length and diameter as explanatory variables, and simple linear regressions including only plant height, were the most accurate to estimate both total above ground dry matter and grain yields per plant (r^2 0.76 to 0.91). Average values for the harvest index ranged between 0.34 and 0.42, describing a curvilinear relationship with total aboveground biomass per plant. Yield estimations on ground area basis for farmers' fields were somewhat less accurate due to the variability in plant density. Plant height measurements can be easily taken at any moment after maize flowering, and used in simple linear regression models, providing acceptably accurate estimations of maize yield.

Completed Work

Exploring diversity in soil fertility management of smallholder farms in western Kenya. I. Heterogeneity at region and farm scale

P. Tittonell, B. Vanlauwe, P. A. Leffelaar, E. Rowe, K. E. Giller

The processes of nutrient depletion and soil degradation limiting productivity of smallholder African farms are spatially heterogeneous. Causes of variability in soil fertility management at different scales of analysis are both biophysical and socio-economic. Such heterogeneity is categorised in this study, quantifying 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) representing the variability found in the highlands of western Kenya. Farm system models were developed for five representative farm types that were identified using information on production components of the farm system, farm assets, family structure, labour and income sources, and considering household objectives and 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. The farm system models were consistent across sub-locations. Farm types 1 and 2 were the wealthiest, though the former relied on off-farm income and farmed small pieces of land while the latter farmed large land areas mainly with cash crops. The poorest farm type 5 also farmed small pieces of land and relied on low wages derived from working for wealthier farmers. Farms of types 3 and 4 were intermediate representing diverse crop production strategies for self-consumption and the market. Differences in household wealth and production orientation between farm types were reflected in the patterns of resource flow at farm scale. Nutrient resources and land management practices (e.g. fallow) also differed enormously between sub-locations. Both inherent soil properties and management explained the variability found for soil fertility status. Texture explained the variation observed for soil C and related total N between sub-locations, whereas P availability varied mainly between farm types as affected by input use.

On-going Work

Construction of wealth classes and farm typologies to guide the implementation of site-specific integrated soil fertility management options in Eastern Uganda and Western Kenya

J Ogada, G Okello, A Muriuki, and B Vanlauwe

In East Africa, decades of nutrient mining without adequate nutrient replenishment have taken their toll on the soil's nutrient stocks, usually resulting in declining crop yields and land degradation. The need to replenish soil fertility is pertinent, but is no mean task because of the financial implications required to rectify the problem. The 'Farm Gradients' project, is attempting to tackle the problem and its goal is to develop a common framework for farmers, researchers and extension agents to assess and manage within-farm soil fertility gradients in an effort to develop more relevant fertilizer recommendations assuming that within-farm soil fertility gradients exist and vary according to site, inherent soil properties, farmer management style and farmer resource endowment.

In 2003, the Farm Gradients project characterized 250 farms in 3 benchmark sites located in 6 districts East African: western Kenya (Siaya and Vihiga), eastern Uganda (Tororo and Mbale), and central Kenya (Meru South and Mbeere). Soil analyses revealed that within farm soil fertility variation is widespread in East Africa's smallholder farms and that there are large differences between districts. One of the next logical steps in order to explain the main drivers for the creation of this variability in soil fertility status at the farm level is to construct wealth classes or farm typologies, knowing that farmers' access to resources is likely going to influence the options that farmers have to manage their soils. Such information will also guide future activities aiming at developing and testing farm class-specific soil fertility management options.

It is envisaged that the study will involve socio-economic surveys, farm mapping, participatory wealth class identification, and multivariate analysis to cluster various households along similar classes. Another important aspect of the study will be to test the robustness of farmer classification across the various target districts. The studies will be carried out in eastern Uganda (Tororo and Mbale) and western Kenya (Vihiga and Siaya) districts and will commence immediately.

Understanding field-specific soil fertility management based on resource flow analysis and identification of local soil quality indicators in Eastern Uganda and Western Kenya

J Ogada, G Okello, A Muriuki, and B Vanlauwe

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It is envisaged that the study will involve construction and interpretation of resource flow maps and documentation of local plants and soil characteristics commonly used by farmers as indicators of soil quality, backed up by conventional soil analyses, identification of common soil fertility management practices and farmer perceptions on linkages between soil management practices and soil quality. The studies will be carried out in eastern Uganda (Tororo and Mbale) and western Kenya (Vihiga and Siaya) districts and will commence immediately.

Building and Sustaining Partnership for Enabling Rural Innovation in Africa: Lessons from multi-institutional partnership that links smallholder farmers to markets

Draft journal paper

Agricultural research and development organizations are increasingly under pressure to build partnerships with a range of stakeholders, institutions and organizations of different characteristics, sizes, levels and objectives. What is not obvious however, is how to build such partnerships, and to cope with obstacles and challenges to effective partnerships to make small-scale farming more market orientated. This papers reflects on partnership experience of Enabling Rural Innovation (ERI), a multi-institutional and multi-stakeholder partnership between international and national agricultural research institutes, extension services, non governmental organizations, farmers' organizations, and the private sector for linking farmer participatory research and market research in a way that empowers farmers to better manage their resources and offers them prospects of an upward spiral out of poverty. The paper highlights several important factors that contribute to the success of partnership, and discusses strategies used for coping with the obstacles to quality partnerships. Critical success factors include a shared vision and belief in community-based participatory approaches, strong and consistent support from senior leadership, joint resources mobilization and resources sharing, evidence of impacts and mutual benefits, and sharing credit and recognition. Other important factors include building human and social capital through interpersonal relationships and friendships, training events and joint field visits, regular communication and information sharing. The changing policy environment, and current reforms in agricultural research emphasizing partnerships and participatory approaches, provides a conducive environment for quality partnership. However, sustaining quality partnerships is challenging. This requires creative strategies for coping with some obstacles such as staff turnover and over commitment, expectations of individual benefits, sustainable funding mechanisms, and challenges of institutionalizing partnerships beyond individual personalities. Overcoming the challenges of quality public-private partnerships between agricultural research institutions, government services and private sector, especially business services and market institutions, will be critical for achieving success in linking smallholders farmers to markets.

Typologies developed to relate household resource endowments to on-farm soil fertility gradients and their management

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[1]TSBF-CIAT; [2]Wageningen Agricultural University; [3]Makerere University, Uganda; [4]Egerton University, Kenya

To study the social aspects of within-farm soil fertility gradients, a survey was conducted in eight sub-locations in Western Kenya (Ebusiloli and Emusutswi, Vihiga District; Nyalgunga and Nyabeda, Siaya District) and Eastern Uganda (Kayoro and Kalait, Tororo District; Busumbu and Mbale, Mbale District), using participatory methods (facilitated community meetings and small group work with key informants) to be followed up with formal interview schedules. The study provides a baseline for characterizing the reasons underlying the differential management of local farms (various fields), addressing both internal (e.g., resource endowment), and external (e.g., access to input/output markets) factors. The indicators of wealth and soil fertility management practices identified are now being used to both a) determine the degree to which the households identified through the spatially-guided "Y-sampling" process are representative of their communities (i.e.: the sub-locations the Y's are designed to characterize) and b) to provide a resource-endowment basis on which to stratify the sample population. On this second point, ten informants have been randomly selected from each wealth class to carry out a resource flow mapping exercise after the survey.

Many of the wealth indicators mentioned were common to all sites. These included livestock, farm size, access to transport; use of hired labour; use of rented land, use of inorganic fertilizers, the food security afforded by the crops harvested from the farm, reliance on off-farm income, and reliance on-farm income such as cash crops or the sale of milk. In general, the community members who met in each of the study sites provided very comprehensive lists of criteria that would distinguish three wealth classes (high, medium, and low) relevant to the ability to manage agricultural land. Examples of these criteria are given in Tables 25a and b for Ebusilloli sub-location in Kenya, and are typical of the criteria and subsequent partitioning of households generated in the other sites.

Table 25a: Indicators of the various wealth strata, Ebusiloli sub-location.

Main indicators		
Abenyalilwanga (Class 1)	**Abatemanga/Ba'akari** (Class 2)	**Abenyalilwanga hati** (Class 3)
Hire in land (3-5 parcels)	Some hire in land 2/3 parcels	Hire out land (part of it) to I, II
Hardworking	Hardest working – family labour, hope to improve harvest, income	Hardworking, on class I farms, no time for themselves
Use inorganic fertilisers	Use inorganic ~ as recommended on part of their farms, FYM on remaining sections	No inorganic ~, few use ~ but as recommended
Hire in labour mainly	Family labour with support from hired in labour	Hire out labour
Certified seed	Certified seed – season I, 'local' seed – season II	Mainly depend on 'local' seed
Appropriate livestock management (zero grazing, commercial feeds)	Free range grazing (dry period), zero grazing (wet season)	Fresh banana residue, tethering, cut grass etc
Cattle, 3 + =Grade + cross + local breeds	Cattle 1-3 = grade + cross + local breeds	Cattle, appx. 1-2
Early agric activities i.e. crop husbandry	Timely agric activities	Late to very late activities. Some skip e.g. weeding. Top dressing
Appropriate soil conservation measures, e.g. terracing, hired labour	Maintained terraces – partly by hired labour, crops on top of terraces	Poorly maintained terraces, and other soil conservation structures
8+ months Food (harvest) secure, July – Dec - march	3-5 months food (harvest) secure	1 months food (harvest) secure
3+ meals a day, balanced diets, meat is frequently part of diet	3+ meals a day, balanced diets, meat is not frequently part of diet	2 meals a day, usually. Few only have dinner (s. potatoes), not balanced diets
1-2 acres of Tea and other cash crops	Appx. ¾ acres of tea, other cash crops	Not tea or other cash crops
Off-farm income: pension, rental houses, salary, remittance, business (retail shop); On-farm income: milk, tea, etc.	Off-farm income: few have low-paying-job: pension, salary, remittance, small rental houses or business (retail shop); On-farm income: 'less' milk, tea, etc.	Wage labour, few children are herds boys, maids, few can sell milk from *okhwechekhwa*[1] cows, sell Napier, stover etc
Transport – wheelbarrows, donkey carts, hired labourers	Transport – few have wheelbarrows, mostly family labour, bicycles	Transport – family labour
Seek **veterinary** services for most livestock diseases	Seek **veterinary** services depending on type of livestock diseases, sometimes rely on herbalists	Mostly rely on herbal livestock doctors
Sell surplus FYM, @ 50≠ per wheelbarrow	Buy FYM. Some buy and sell (trade) FYM	Do not buy FYM. Some rely on *okhwechekhwa* animals, gift from class I.
Buy Napier, @ 20≠ per bundle (local cows would need 6/day)	50-50, sell or buy Napier	Sell Napier for income, do not give their livestock

[1] Means "to give out livestock" under an agreement that allows the keeper to derive all the benefits, including sale of milk, except selling the animals.

Table 25b: Distribution of households in social strata, Ebusiloli.

Site (Village)	Classes			
	Class 1 (10%)	**Class 2 (61%)**	**Class 3 (29%)**	**Total**
Emanyonyi	9	96	22	127
Mwilonje	10	65	42	117
Mukhombe	18	57	25	100
Wobaria	10	54	39	103
Total	47	272	128	447
Per cent	**10**	**61**	**29**	**100**

Interestingly, in all of the discussions there tended to be very few households that could be identified as Class 1 (usually a term translated as "wealthy" or "rich") and there were often highly contentious discussions about who qualified as Class 2 or 3. There were also intense debates about whether to allow a Class 4 to reflect socially problematic households whose members were perceived as "lazy", "drunkards", or other deviations from the expected norm of rural behaviour. Inevitably these households were ultimately included in Class 3.

While there is great disparity between the extremes of "high" (wealthy) and "low" (poor) resource in any given site, there is also extreme variation between the averages endowments of the eight study sites. This is also true for the bio-physical data being collected, and complicates the potential for cross-site comparisons of behaviour and performance. The challenge for the coming year is to meaningfully abstract and integrate the relationships between wealth class, soil fertility status, and management practices to present findings that are relevant to the studied areas without being too simplistic or dilute in their explanatory power.

Challenges to successfully scaling up knowledge-intensive ISFM regimes

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Paper presented at AFNET Symposium in Yaoundé, 17-21 May, 2004

Smallholder farmers in Sub-Saharan Africa significantly depend on land for their livelihoods. Nevertheless, these livelihoods are constrained by inherent low soil fertility. For many decades, researchers and farmers have battled to arrest soil fertility degradation. Over the last decade, this battle has resulted in the development of Integrated Soil Fertility Management (ISFM) technologies. Between 2001 and now, TSBF researchers and local smallholder farmers in western Kenya have been adapting these technologies to local circumstances under the community-based initiative called "Strengthening Folk Ecology". This initiative involved participatory demonstration-trials and dialogue as principal methods in the learning and adaptation process. Follow up studies have been undertaken to identify successful cases of this process. Initial results showed that although such cases are not widespread, they are promising and benefits are to be scaled up for wider use by farmers in areas beyond the project sites.

Nevertheless, scaling ISFM technologies is complicated. ISFM technologies are knowledge-intensive and demanding, and their adaptations and applications are diverse. Scaling up ISFM technologies should therefore involve simple practical processes, sustained dialogue over long periods aimed at knowledge generation and sharing. This paper provides insights into this topic by discussing selected ISFM technologies with regards to their inherent scalability.

This review of ISFM technologies, with regards to the possibility of scaling up shows two vital lessons. Firstly, those ISFM technologies were applied in different ways; their use results in a complex knowledge generation process amongst farmers, by building on the power of the natural sciences. Secondly, it is difficult to generate and extrapolate knowledge-generation processes for scaling up. Farmers based their knowledge generation processes on the balance of possibilities after evaluation of the available evidence and on the basis of longterm experience. Therefore, scaling up ISFM technologies should focus on mastering soil ecological processes rather than the "facts" of yield data generated in experimentation events, which lead to the impression that research is about certainties. Scaling up ISFM should consist of simple practical processes that farmers can understand, adapt and share with other farmers while interacting with researchers. This can still be done in "classical" on-farm experiments, such as simple plots of screening grain legumes such as promiscuously nodulating soybeans, but needs to focus more on the residual and interactive effects of the legumes with the rest of the system. With time, local farmers will generate useful knowledge regarding how these legumes respond to their highly varied soils. Such a research process needs long-term farmer empowerment and dialogue that leads to demystification of science from "known certainties and facts", to continuous processes that generate better opportunities.

TSBFI-Latin America

Published Work

Increasing the relevance of scientific information in complex hillside environments through understanding of local soil management and agronomic uncertainty

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Soil Use and Management 20: 23-31

This article explores the question of how scientific information can improve local agronomic management using concepts of uncertainty classification and uncertainty management. Information and data on local soil fertility management based on a local classification system of soil quality were collected from a small watershed in Cauca (Colombia). The analyses suggest that farmers hold local knowledge about soils at two levels. The first is based on empirical observations and refers to local knowledge about soils, which shows that the classes identified in the local soil quality classification are consistent with results obtained using measured soil parameters. At a second level, farmers have some awareness of ecological processes and appropriate use of relationships between key soil characteristics and management options. It is argued that local knowledge is not sufficient to cope with uncertainty introduced by a rapidly changing agriculture, including, increasing land pressure, unpredicTable market forces and climate change. We have suggested how scientific knowledge can contribute to the solution, based on an analysis that relates Cohen's (*Hueristic reasoning about uncertainty: an artificial intelligence approach.* Pitman London, 1985) and Rowe's (*Risk Analysis* 14, 743-750, 1994) uncertainty concepts to local knowledge.

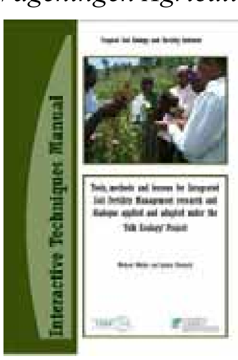
Activity 1.6 Methods for integrating and strengthening local and technical knowledge of soil processes, soil quality, ecosystem services and BGBD developed

TSBFI-Africa

Completed work

Interactive Techniques Manual: Tools, methods and lessons for Integrated Soil Fertility Management research and dialogue applied and adapted under the 'Folk Ecology' Project

M.T. Misiko[1]; J.J. Ramisch[2]; J. Mukalama[2]
[1]*Wageningen Agricultural University;* [2]*TSBF-CIAT*



This manual presents and discusses methods and tools applied under the "Strengthening Folk Ecology" project. It is a descriptive and analytical summary of how those methods and tools were developed, applied, and how they have continued to be adapted and combined for different circumstances. Rather than simply offering another "toolkit" for practitioners and farmers, the main discussions focus on key lessons learned about the application of those tools and methods under the project.

The “Folk” Ecology project was a community-based interactive learning initiative. Its focus was to broaden farmers’ soil fertility management strategies by incorporating scientific insights of soil biology and fertility into their repertoire of folk knowledge and practical skills. The major objective of the “folk” ecology project is to develop innovative and interactive learning tools that facilitate the exchange of knowledge and skills between farmers, scientists and other agricultural knowledge brokers.

To achieve its goals, the project first undertook community-level studies on local soil fertility practices and perceptions using several mainly qualitative methods and tools. These methods and tools have been described and discussed in section two of this manual. The third part provides “folk” ecology interactive learning approaches and experiences. This manual is divided into four parts: part one, summary on useful theoretical background relevant to “folk” ecology; part two, tools for community-based studies; part three, the “folk” ecology interactive approaches and experiences; and part four, application of the manual.

Generating “dynamic expertise”: Strengthening “Folk Ecology” and Integrated Soil Fertility Management

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Poster presented at the Eco-agriculture Conference, Nairobi, Kenya, 27 Sept – 4 Oct, 2004

The expertise small holder farmers use to manage their agro-ecosystems is “dynamic” in that it responds to local logic and ever-changing bio-physical, climatic, and economic environments. “Dynamic expertise” is thus rooted in the local knowledge system (“Folk Ecology”) that smallholder farmers use to interpret new ideas and research findings. Participatory research methods integrate local knowledge with the knowledge of outsiders (researchers, other experts) to build the “dynamic expertise” that empowers farmers to apply knowledge to practical situations.

This poster presents experience with generating dynamic Integrated Soil Fertility Management (ISFM) expertise among farmers in rural western Kenya. This process formed part of the Strengthening “Folk Ecology” project, a community-based interactive learning initiative of the Tropical Soil Biology and Fertility Institute (TSBF). The “Folk” Ecology project generated dynamic expertise through dialogue and hands-on strategies to understand how farmers’ local logic would influence outcomes of project work, such as the incorporation of elements of new technologies into the farming system. Evidence of dynamic expertise included: new farmer experiments, enhanced capacity for local institutions and networks, and new “language” for new knowledge and skills.

On-going Work

Increasing understanding of local ecological knowledge and strengthening interactions with formal science strengthened.

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Work with communities in four sites of western Kenya since 2001 has established that these communities do indeed possess and use a functioning local ecological knowledge system, which we have designated a “folk” ecology to distinguish it from the “formal” or systematized “science” of ecology. This “folk” ecology follows its own consistent logic and 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 folk ecologies apparent through an iterative dialogue between farmers within farmer research groups (FRGs) and between farmers and researchers (see Figure 27 – Strengthening Folk Ecology). Making “folk” ecology 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.

For a number of reasons, understanding (and then enriching and broadening) “folk” ecological knowledge is an extremely long and complex process. We used integrated soil fertility management

(ISFM) as an entry point for community activities largely because TSBF's strength is in improving soil management. However, because of the embedded nature of "folk" ecology, the activities and innovations of the community-based learning process have extended well beyond purely addressing "soil fertility". The depth and quality of "folk" ecological knowledge varies widely between actors, even within relatively homogenous communities, such that it is difficult to generalise "who" knows "what" (i.e.: to identify "women's knowledge" as such, etc.) The local institutions involved (FRGs, kinship and marriage networks, etc.) are themselves also extremely complex and often volatile, with memberships, priorities, and motivations that can change substantially over time. Similarly, "folk" ecological knowledge relating to soil management is rarely conceived of separately from broader livelihood concerns and priorities. The goal throughout will be that "folk" ecology 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 PhD-level researchers.

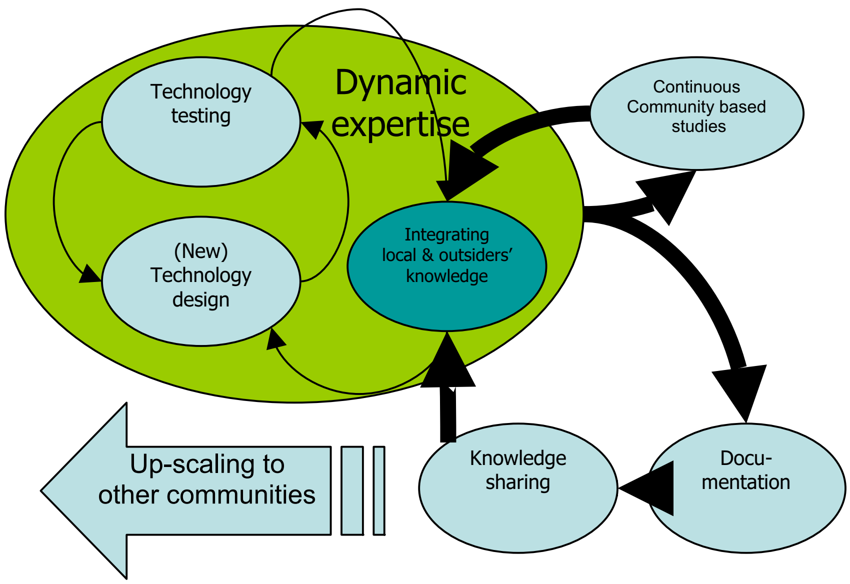

Figure 27. The Strengthening Folk Ecology process. Dialogue and group activities that form part of the "Integration of local and insiders' knowledge" feed into an iterative process of collective and individual technology design and testing, which leads to the generation of local "dynamic expertise" for 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.

Future work will build on the achievements of the first phase by documenting the dynamics by which "folk" ecological knowledge is generated, shared, or withheld in the institutions involved in the research so far. These institutions include the formally constituted groups (i.e. FRGs, women's groups, etc.) as well as informal community networks such as those of kinship, marriage, or friendship, commercial or patron-client relationships. Participant observation of key informants and of the functioning of the FRGs demonstrated that "folk" ecology 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. For example, many of the FRGs used fairly researcher-designed demonstration or experimentation activities of soil fertility management as a starting point but have since evolved their own unique sets of activities incorporating local logics and priorities. The experimentation is now much more distributed to multiple individuals within the FRGs with various ways of sharing findings within each context. The emphasis of activities has also shifted from "purely" soil improvement to food security issues, and test crops now cover everything from local vegeTables to root crops to legumes and cereals. In all the sites, FRGs now engage in various co-learning activities such as drama groups, small discussion circles, and self-help financing.

The increasing diversity of activities requires substantial follow-up, which will be implemented through a participatory monitoring and evaluation (PM&E) process that will both: a) determine how FRGs' innovations can be supported and enriched with inputs from partners or each other and also b) feed the FRGs' lessons into on-going farmer-researcher dialogue. Combining the outputs of the farmer-driven PM&E and more researcher-driven documentation process will generate appropriate co-learning activities, experiments, and materials to support improved decision-making for managing the local agro-ecosystems.

Finally, we are reinforcing the successes of the first phase by following the transmission of knowledge within FRGs, and also the modes in which technical people and farmers interact, with the goal of comparing the information content and outcomes that result from different generations of interactions. This component of the project will allow us to derive general principles about how to "unbundled" complex knowledge (such as that involved in managing soil-germplasm-climate-livelihood technologies) and how to better communicate improvements to that knowledge.

Do farmers really manage soil fertility?

M.T. Misiko[1], J.J. Ramisch[2], J. Mukalama[2], Ken Giller[1]; Paul Richards[1]
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Paper in preparation

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 positive vitality of) local logic is the best approach to enhance soil fertility management among smallholder farmers of western Kenya.

A South-South development of a methodological guide for linking technical and local soil knowledge for designing Integrated Soil Fertility Management options

Barrios, E., Delve, R.J., Bekunda, M., Mowo, J., Agunda, J., Ramisch J., Thomas, R.J.

Draft journal paper

The increasing attention paid to local soil knowledge in recent years is the result of a greater recognition that the knowledge of smallholder farmers can offer many insights into the sustainable management of tropical soils. In order to capture this local knowledge and link it with technical knowledge systems, a participatory approach in the form of a methodological guide has been developed to identify and classify local indicators of soil quality related to technical soil parameters. This methodological guide was initially developed and used in Latin America and the Caribbean (Honduras, Nicaragua, Colombia, Peru, Venezuela, Dominican Republic), and was later improved during adaptation and use in the East African context (Uganda, Tanzania, Kenya, Ethiopia) through a South-South exchange of expertise and experiences. Valuable contributions from collaborators in Africa have now been incorporated into a new Spanish version of the methodological guide *via* a full reciprocal South-South exchange cycle. This methodological tool aims to empower local communities to better manage their soil resource through better decision-making by fostering the development of a local soil quality monitoring systems. It is also designed to steer soil management towards developing practical solutions to identified soil constraints, as

well as, to monitor the impact of management strategies implemented to address these constraints. Farmers become aware that some local and technical indicators can provide early warning about unobservable changes in soil properties that later lead to visible soil degradation. The methodological approach presented here constitutes one tool to capture local demands and perceptions of soil constraints as an essential guide to relevant research and development activities. A considerable component of this approach involves the improvement of the communication between the technical officers and farmers and *vice versa* by jointly constructing an effective communication channel. The participatory process used is shown to have considerable potential in facilitating farmer consensus about which soil related constraints should be tackled first and what potential soil management options could be used. Development of local capacities for consensus building is presented as a critical step prior to collective action by farming communities resulting in the adoption of integrated soil fertility management strategies at the farm and landscape scale.

CSM-BGBD project - methodology and inventory

This year, significant progress was made in the GEF funded CSM-BGBD project in all the participating countries in terms of methodology development and inventory of below-ground organisms. Functional groups of soil organisms, for which the inventory by prescribed standard methods was mandatory, were clearly defined and assigned to all the participating countries. A list of optional functional groups, with all the attendant methods for their inventory, was developed in consultation with the partners.

- Standard methods for the inventory of the soil organisms developed and circulated to project partners in seven countries in three continents. The countries are Brazil, Cote d'Ivoire, India, Indonesia, Kenya, Mexico and Uganda. The functional groups whose inventories were considered manadatory include: legume nodulating bacteria (LNB), Arbuscular Michorrhizal Fungi (AMF), Phytopathogenic Bacteria (i.e. Pseudomonas, Ralstonia, Erwina, Xanthomonas), Ectomycorrhizae, Soil Borne Fungi (i.e. Phythium, Fusarium, Rhizoctonia), Entomopathogenic Nematodes, Nematodes (i.e. plant pathogens and free-living pathogens), Mesofauna, Macrofaune (i.e. ants, beetles, termites, and earthworms) and finaly palnt pests (i.e white grubs or commonly known as fruit flies.
- Collecting samples for inventory of BGBD and site characterization of benchmark sites completed in Brazil.
- Fieldwork for first project phase completed in Mexico. Sample analysis is underway. First results of the inventory of earthworms and nematodes presented to a stakeholders workshop.
- Indonesia completed field work for two benchmark areas. Taxa have been determined for 8 groups of soil biota. Inventory of pests and disease is underway.
- Uganda has completed fieldwork for site characterization and BGBD inventory.

Activity 1.7 Participatory and formal economic methods of valuating soil management practices developed and tested

TSBFI-Africa

Completed work

Financial benefits of *Crotalaria grahamiana* and *Mucuna pruriens* short-duration fallow in eastern Uganda

J.B. Tumuhairwe, B. Jama, R.J. Delve, M.C. Rwakaikara-Silver

Revised article submitted to African Crop Science Journal

Crotalaria grahamiana and *Mucuna pruriens* improved fallows are gaining popularity among smallholder farmers in Uganda to address soil fertility decline. The technology supplies nutrients and increases crop yields but its economic viability is uncertain in eastern Uganda. Therefore, two researcher-managed experiments were established in Tororo District, eastern Uganda to determine the financial benefits of the *C. grahamiana* and *M. pruriens* improved fallow compared to farmers' practices of natural fallow, compost manure and continuous cropping. Higher returns to land were obtained from improved fallow compared to farmers' practices. *C. grahamiana* realized US$267.4 (Dina's site) and $ 283.2 (Geoffrey's site), and *M. pruriens* had $284.1 (Dina's site) and $248.7 (Geoffrey's site) compared to natural fallow $223.3 (Dina's site) and $274.3 (Geoffrey's site), compost manure $70.9 (Dina's site and 114.2 (Geoffrey's site) and continuous cropping $314.2 (Dina's site) and $314.2 (Geoffrey's site) per hectare. Improved fallows saved on labor compared with continuous cropping and compost manure except for natural vegetation fallow. Higher returns to labor were obtained through use of improved fallow than compost manure and continuous cropping. Returns to labor of $0.54 day^{-1} were obtained for compost manure (at Dina's site), which is less that the wage rate at $0.57 day^{-1} indicating a loss in labor invested.

Profitability analysis and linear programming to optimize the use of biomass transfer and improved fallow species for soil fertility improvement

P.N. Pali, B. Bashaasha, R. Delve, R. Miiro

Submitted to African Crop Science Journal

Studies that have focused on the economics of integrated soil fertility management technologies have predominantly used the partial budgeting and Economic Rate of Return (ERR) analytical tools, whilst studies that have used the linear programming (LP) technique have been restricted to the evaluation of perennial cropping systems including agroforestry. This paper uses a partial budget analysis and LP to determine the optimal combination of management practice and profitability of using organic and inorganic soil improvement options. The incorporation of 100% or 50% of the above-ground biomass of improved fallow (IF) species *Mucuna pruriens* and *Canavalia ensiformis* and the biomass transfer (BT) species *Tithonia diversifolia* are the focal soil improvement practices (SIP) considered in this study. All SIP were more profiTable then farmers existing practice, with BT being more profiTable than IF, especially when BT was used in combination with inorganic N fertilizers. For IF the optimal SIP was found 50% Mucuna and 100% Mucuna application. Under the optimal solution 0.81 ha, 218.1 labor days and an investment of 327,150 Uganda Shillings would be required to obtain the optimal benefit of 188,867 Uganda Shillings over three cropping seasons would require For BT the application of 0.91 t ha^{-1} of Tithonia with 30 kg N ha^{-1} would produce the highest net benefits of 445,744 Uganda shillings ha^{-1}, with a 16% lower optimal net benefit solution of 372,069 Uganda Shillings, on 0.83ha, using 105 labor days. The IF and BT options considered were all profiTable and the production objectives and constraints of smallholder farmers is the only constraint to their adoption.

Determinants of the adoption potential of selected green manure and legume species in eastern Uganda

P.N. Pali, R. Miiro, R. Delve, B. Bashaasha, E. Bulega.

Submitted to African Crop Science Journal

Abstract: Agricultural production in sub-Saharan Africa is declining due to increasing population pressure on the land. A resultant feature is the dependence on external inputs to attain crop yields at and above a subsistence level. This paper evaluates the acceptance of one low cost approach to overcome high input costs, the use of green manure and legume species in Eastern Uganda. The eight shrubs of main focus were *Mucuna pruriens, Canavalia ensiformis, Tithonia diversifolia, Sesbania sesban, Crotalaria ochroleuca, Calliandra calothrysus, Dolichos lablab, and Tephrosia vogelli.* It focuses on the determinants of decisions to utilize these technologies and farmer perceptions of the management of these innovations. A survey of 108 farm households using a structured questionnaire and focus group discussions (FGD's), were the main data collection tools. The data were subjected to descriptive statistics and Probit regression modeling analytical techniques. The factors that explained technology acceptance were insecticide use, household size, cultivated area, perception of soil improvement technology following use, education, and wealth. *Sesbania* and *Mucuna* were found to be the most popular and

problematic tree and shrubs respectively. Reported benefits related to sustainable utilization and improved livelihoods through shrub and tree technologies included increased yields, soil texture, soil structure improvement, erosion control and alternative uses of shrubs and trees

Competitiveness of agro-forestry based soil fertility management technologies for food production: the case of small holder food production in western Kenya

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Paper submitted to African Crop Science Journal

Persistent food insecurity accompanied by low and declining farm house hold incomes are a common feature of many small holder maize and bean producers. This has been largely attributed to soil nutrient depletion among other factors. One way of addressing soil fertility problems in many maize-based cropping systems is the use of agro-forestry based technologies. A survey was carried out in Vihiga and Siaya districts of western Kenya. The Policy Analysis Matrix (PAM) method was used to determine the social and financial competitiveness of different production systems which were categorized on the basis of the technology used to address soil fertility. Farm budgets were first formed and in turn used to construct the PAMs for six production systems namely: maize-bean intercrop without any inputs, maize-bean intercrop with chemical fertilizers only, maize-bean intercrop with chemical fertilizers and improved fallows, maize-bean intercrop with improved fallows only, maize-bean intercrop with improved fallows and rock phosphate, and maize-bean intercrop with farm yard manure (FYM) only (see Table 26 and 27).

Table 26. Financial profitability.

Production system	Revenue	Tradable inputs	Domestic factors	Profits
M/B+0	15,226	0	8,200	7,026
M/B+F	18,300	1,430	7,549	**9,321**
M/B+F+IF	19,443	802	8,603	**10,038**
M/B+IF	13,099	0	9,101	3,997
M/B+IF+RP	14,870	330	8,884	5,657
M/B+FYM	16,990	0	8,600	8,390

Table 27. Social profitability

Production system	Revenue	Tradable inputs	Domestic factors	Profits
M/B+0	10,926	301	5,609	5,016
M/B+F	12,667	807	5,099	6,761
M/B+IF+F	15,991	1,210	7,411	**7,370**
M/B+IF	11,000	580	7,789	2,631
M/B+IF+RP	12,210	1,001	6,161	5,044
M/B+FYM	13,100	701	5,422	**6,977**

Note: M/B=maize-bean intercrop; M/B+0= maize-bean intercrop with no external inputs; IF=Improved fallows; F=Chemical fertilizers; RP=Rock Phosphate; FYM=Farm Yard Manure; M/B=maize-bean intercrop

Use of the combination of chemical fertilizers with improved fallows was the most financially and socially profiTable production system, with profits of Ksh 10,038 and Ksh 7,370 respectively. Use of Farm Yard Manure (FYM) gave the third highest financial profits of Ksh 8,390 and also the second highest social profits (Ksh 6,977). One thing which is clearly observable from the production systems is that use of chemical fertilizers enhanced the financial profits gained from use of improved fallows. However, due to price constrains in relation to chemical fertilizers, it can be concluded that use of FYM can be both an affordable and profiTable technology package for the production of maize and beans.

There is need for retailers selling chemical fertilizers to consider repackaging it into small quantities (like 100g, 200g and 300g) which can be affordable to farmers. Also, farmers should be encouraged to use Farm Yard Manure (FYM) though it ranked third in terms of private profitability and second in terms of social profitability.

On-going Work

Characterization of smallholder farm typologies in maize-based cropping systems of central Kenya: use of local and technical soil quality indicators

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Paper presented at the Soil Science Society of East Africa (SSSEA) conference, 29 Nov-3 Dec, 2004, Arusha, Tanzania

In recent years, integrated soil fertility management (ISFM) paradigm has emerged as best strategy for resource-poor smallholders to mitigate food insecurity and poverty problems. Such farmers are heterogeneous in terms of resource endowments and therefore pursue different soil fertility strategies to combat nutrient depletion. However, hunger, malnutrition and poverty have escalated in most smallholder cropping systems. This makes characterisation and evaluation of ISFM technologies under different socio-economic and biophysical farmers' circumstances more imperative. The study examined how local and technical soil quality indicators (LSQI and TSQI) could be used to delineate farmers in maize-based cropping systems of central Kenya into different inter- and within-farm recommendation domains. Methodologies used included Participatory Learning and Action Research (PLAR) for classification of farmers into different soil fertility management (SFM) and resource endowment classes. Depending on levels of organic and inorganic fertilizers, soil conservation structures and depth of tillage, three classes of farmer emerged: class I (good SF managers), class II (medium SF managers) and class III (poor SF managers). Correlation coefficient (r) and Analysis of variance (ANOVA) were then employed to validate LSQI- and TSQI-based classification. Correlation coefficient (r=0.5) indicated a positive relationship between SFM and wealth-endowment variables. Results depicted significant differences ($P<0.05$) in mean % Carbon, % Nitrogen and ppm Phosphorous within and between different classes. Carbon ranged from 1.4% in Kirinyaga to 2.1 % in Maragwa, while Nitrogen ranged from 0.06-0.17 % in two districts respectively. Kirinyaga had highest Phosphorous levels (649 ppm) while Maragwa had the lowest (45 ppm). The study results could therefore, help develop more participatory and targeted ISFM technologies to suit different recommendation domains, for enhanced productivity of smallholder agro-ecosystems.

Table 28a. Wealth ranking in Kariti and Mukanduini study sites.

Wealth Indicator	Class I	Class II	Class III
Level of Education	College and above	Secondary school level	Primary education and below
Off-farm Income	Permanent employment	Small Business	Casual, no off-farm income
Land Size	> 2 acres	1.5 – 2 acres	< 1.5 acres
Type of Farmhouse	Permanent House	Semi-permanent House	Mud house
Livestock Type and #	> 2 Cows	1 cow	None

Class 1 uses highest levels of manures and commercial fertilizers, constructs soil conservation structures and practices deep tillage. Class 2 farmers uses manures and fertilizers but at lower levels than class1 and have some soil conservation structures, while class 3 uses least fertilizers and manures levels and have poorly maintained soil conservation structures. Also different farm portions were classified as fertile, medium or poor depending on farmer-perceived local soil quality indicators (LSQI).

Table 28b: Correlation of SFM and Wealth endowment in Kariti and Mukanduini

Site	Class I	Class II	Class III	Corr. Coeff. (r)	t_0
KARITI	44	55	194	0.46	9.2
MUKANDUINI	7	74	192	0.63	14.3

Corr. Coeff. = Correlation Coefficient, t_0 = Observed t value

Classification of farmers in study sites based on their wealth status resulted also in three classes. This classification was paramount as it identified important farmers' socio-economic circumstances, which are critical determinants in adoption of soil fertility management technologies.

Average correlation coefficient (r) in both sites (0.5), indicated a positive correlation between soil fertility management and wealth endowment variables. T-test on r-values (α = 0.05) led to rejection of null hypothesis that there is no relationship between farmers' wealth endowment and their soil fertility management status. This result therefore, indicates that wealthy farmers are also good soil fertility, thus confirming PLAR classification.

Table 29: Technical Soil Quality Indicators (TSQI) for different classes in Kariti and Mukanduini sites

Site	Class	pH	% C	% N	ppm P	Ppm K	CEC
KARITI	I	5.5	2.0	0.17	64	672	6.8
	II	5.6	2.1	0.14	101	606	6.6
	III	5.4	1.8	0.13	45	362	6.4
	$LSD_{(0.05)}$	0.04	0.32	0.02	26.6	228.1	1.72
MUKANDUINI	I	5.6	1.6	0.09	441	410	7.2
	II	5.8	1.5	0.07	632	385	7.9
	III	5.8	1.4	0.06	649	428	6.8
	$LSD_{(0.05)}$	0.66	0.46	0.07	100.3	241.9	1.43

Results indicated significant differences in some technical soil quality indicators (TSQI) between classes and within different portions of same farms. However, some TSQI did not show such significant differences.

Participatory models in fostering farmer innovation to minimize trade-offs and induce win-win benefits: The case of Organic Resource Management

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This work is a continuation of earlier investigations which revealed that there is very strong trade-off for the limited organic biomass (i.e. crop residue, manure, stubble, weeds, grasses and underground biomass) at farm and landscape scales among various uses namely, as a cooking fuel, as livestock feed, as cash generation enterprise and as soil fertility restorer. And yet, the amount of organic biomass in the system is very much limited to satisfy these different needs, which are all probably important but the household decision is made based on priority needs. The objective of this work were to understand farmer experimentation processes to overcome biomass constraint in the system, to document farmer innovations towards solving the problem and to develop farmer-friendly tools & guides to improve farmer-community understanding of their farm & landscape systems for identification of niches. The major steps considered to date were: a) Participatory mapping of the current sources of biomass at plot, farm and mini-watershed-level including crops, forages, trees, valley bottoms, homestead crops and other niches b) participatory estimation of biomass yield per time and space in selected farms c) Monitoring resource flows and production fluctuations at household level in selected farms d) Participatory identification of possible niches for growing more biomass in the system, e.g. integration of high biomass producing, promiscus type legumes, (e.g. Climbing beans, Soybeans) and fast growing and browsing resistant forages (e.g. napier grass).

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

Rationale

Process level information needs to be translated into sustainable soil fertility and land management practices, adapted to the environment in which these practices will be implemented. These environments are characterized by biophysical and socioeconomic traits and those can vary at different scales, from the household (e.g., different access to resources) to the watershed (e.g., different inherent soil quality across landscapes) to the region (e.g., different policy frameworks related to natural resource management). Integration of these factors in the development of sustainable soil fertility and land management practices and understanding on how these factors influence the final outlook and components (e.g., varieties, use of inputs) of these practices is a crucial strategic research issue addressed in this output.

Practices addressed in this output are touching upon various aspects of soil fertility and land management and address the management of these natural resources in the broadest sense, far beyond agricultural production per se. Such aspects include the management of nutrient cycles, belowground biodiversity, ecosystem services, and erosion control. Certain practices are targeting one of these aspects while others are rather integrating more aspects. In terms of improved nutrient cycling, efforts are made to integrate the supply and the demand side for nutrients, and to enhance the use efficiency of organic and mineral inputs. Traditionally, soil fertility management has addressed the supply side of nutrients through concepts such as synchrony, but it is equally important to include the appropriate germplasm that will drive the demand for those nutrients, in soil fertility management strategies.

Efficient use of inputs can be achieved through integration of mineral and organic inputs and targeting soil fertility niches at the farm and landscape scale. Translating strategic information on belowground biodiversity in management practices is expected to happen through management of specific biological pools through cropping system diversification or inoculation or through management of the physical conditions of the soil by integrating conservation agricultural principles. Soil-based ecosystem services are very much related to the quality/quantity of the soil organic matter pool and the regulation of greenhouse gas production and sequestration. Consequently, management of organic resources is paramount to implementing soil fertility and land management practices enhancing ecosystem services. Finally, diversification of contour structures and building up of a soil arable layer is expected to drive the generation of practices restricting erosion and soil physical degradation.

While the above activities are focusing on the technical dimensions of the technology development and evaluation phase, specific activities addressing the socio-economic and policy constraints to the adoption of these options are simultaneously covered. Finally, Output 2 is expected to deliver enhanced farmer capacity to translate best principles for soil and land management into practices that are appropriate to their environment and decision aids, condensing that knowledge, for dissemination beyond the sites where this knowledge has been generated.

Milestones

- By 2006, decision support framework for ISFM developed, tested with and made available to stakeholders in at least 2 benchmark countries.
- By 2008, communities in at least 3 countries demonstrate and test direct or indirect management options that enhance locally important ecosystem services using BGBD.

- By 2010, local baselines and interviews show that farmers' understanding of soil processes is demonstrably enhanced within community-based experimentation in at least 5 benchmark sites.

Highlights

TSBFI-Africa

- Afnet trials have continued in over 20 coutnries in sub-Saharan Africa, on the following themes: the role of micro-organisms in African farming systems, interaction between water management and nutrient management in African Dry Lands, on-farm evaluation of soil fertility restoration technologies, long term evaluation of soil fertility status as affected by tillage and organic and mineral inputs, and others.

TSBFI-Latin America

- In the process of constructing an arable layer, the use of agropastoral systems including legume species, compared to grass species alone, had a greater contribution to labile organic N that resulted in greater soil N availability.
- Predictions generated by the NuMaSS expert system on presence or absence of N deficiency in maize matched the field data on 29 of 31 site-years of on-farm replicated experiments in Honduras and Nicaragua.
- Found that intensive dairy operations based on confined feeding of cut and carry forages result in lower net emissions of greenhouse gases per unit of produced milk, compared to grazing under a silvopastoral system.

Activity 2.1 Strategies for improved nutrient cycling by exploiting variability and intensifying and expanding legume use developed and tested.

TSBFI-Africa

Published Work

Performance evaluation of various agroforestry species as short duration improved fallows for enhancement of soil fertility and sorghum crop yields in Mali

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The human population growth rate in the Sahel (nearly 3% per annum) is among the highest in the world creating a high land use pressure with the disappearance of the traditional fallow system. This has accelerated the degradation of the natural resources base by a poverty-stricken population forced to overexploit soils, rangelands and forests in order to subsist. The consumption of mineral fertilizers in SSA increased slowly by 0.6% during the last 10 years, compared to 4.4% in the rest of the other developing regions. The total annual nutrient depletion in SSA is equivalent to 7.9 Mg yr-1 of N, P, and K, six times the amount of annual fertilizer consumption in the region. In the particular case of the southern Mali region, N-K-Mg budgets in 1992 were estimated to be -25, -20, and -5 kg per hectare per year indicating that as much as 40% to 60% of the income generated by farming in this region were based on "soil mining". It is in the light of these constraints that the Malian agricultural research institute (Institut d 'Economie Rurale, IER), the Sahel Program of the World Agroforestry Centre (ICRAF) and the International Crops Research Institute for the Semi Arid Tropics (ICRISAT) joined efforts to undertake research activities aimed at sustainably improving soil fertility and agricultural crop yields in the Mali. Thus, from the year 2000 14 different trees and shrubs are being tested in improved fallow systems to find which ones perform best to replenish soils and improve crop yields. The results have i) identified most suited species for 1 or 2 yr improved fallows, ii) determined their impact on sorghum grain yields and iii) documented the remnant effects of their impact on soil fertility and crop yields. Some species could not survive more than 1 year the Samanko conditions. In 2002, the first year of cultivation, it was the Kenyan provenances of Sesbania sesban which performed best with sorghum yields over 2 t ha^{-1}. A year later, 2003, there has been a general decrease in crop yield. Again, the Kenyan provenances of S. seban, with yields 40% lower than the first year of cultivation, were the worst affected by this decrease. No significant changes were observed in the traditionally tested chemical soil parameters.

On-going Work

Farmer participatory evaluation of cowpea for soil productivity and food uses

Delve R.J. and Nyende, P.

Draft paper

Dual purpose legumes which offer both reasonable grain yield and biomass for use as fodder or soil improvement are a new product of research that can offer best bet compromise for farmers needing to improve soil fertility and maintain their cash flow, while ensuring food security. New dual purpose cowpea lines developed by the International Institute for Tropical Agriculture (IITA) were evaluated for provision of grain and fodder in addition to improving soil fertility improvement through N fixation. A set of 14 cowpea lines were evaluated against a local check in an on-station trial in Tororo, eastern Uganda with the objectives of i). establishing the agronomic performance of new cowpea lines in the agro-climatic and farming system environment of eastern Uganda; ii) assessing farmers' preference for the different lines for food, fodder and soil fertility improvement and iii) providing the national grain improvement programme with the opportunity to select lines for further testing and use, either directly as varieties or as sources of breeding materials. Results indicated that the local variety, *Ngori*, had the highest level/probability of acceptance compared to the new lines. The acceptability and logistic analyses showed that out of the 14 new lines evaluated, IT98K-205-8 and IT95K-238-3 were the best genotypes. The agronomic results confirmed the above conclusion. Although, IT98K-205-8 did not have the highest yields, its yields were not significantly different from those from IT95K-238-3, which had the highest grain yields. It was also observed that the line (IT97K-1068-7) which had the highest fodder yield produced the lowest grain yield. Although IT98K-205-8 was the most preferred according to the given criteria, the palatability test indicated that of all the new cowpea lines the most palatable one was IT95K-238-3. Cowpea line, IT95K-238-3 came out as the best lines in terms of palatability, acceptability and yielding potential. At the end of the research farmers who participated in the evaluations selected the best five lines for further evaluation and seed multiplication. This trial therefore, has provided farmers in this region with a wider spectrum of dual purpose grain legume lines from which they can choose from depending on whether they need grain, fodder or soil improvement.

Data/information coherence and integration: Challenges and Implications for augmenting decision-support systems for soil fertility management

Bagenze, P., Delve, R.J. and Huising, J.

Draft paper from on-going M.Sc. thesis

Various datasets on agronomic practices exist to facilitate decision-making and implementation on agronomic issues. The varying quality, scale, and thematic detail of these is not presently integrated and the databases *per se* do not provide suitable decision support recommendation criteria, especially in identifying and selection of area-specific domains for agro-technology transfer. Targeting such technologies to the most promising niches entails having not only information on the technology and the niches to be targeted but also having this information/data in a format compatible with multi-decision support systems to be used for dissemination. Most of the existing technology transfer recommendations are based on very general guidelines. Trials have normally been carried out on a few research stations and little effort is made to make the observations on these research stations meaningful beyond the research station boundaries and applicable to a typically heterogeneous tropical environment targeted. This kind of information does not *per se* provide sufficient grounds upon which to base reliable technology recommendations beyond trial sites, as there is not adequate consideration of the respective spatial and temporal conditions. The on-station research findings albeit meaningful, only form part of the comprehensive package of variables both biophysical and socio-economic, which are rarely considered when choice of decision support systems for disseminating technologies is undertaken and yet have a great bearing on identifying appropriate areas to target. This paper reviews steps for identification and choice of appropriate data/information and decision support systems that can augment successful land management recommendations. It discusses the use of an array of integrated research and extension tools ranging from basic process research, to widespread on-farm targeting, verification and the use of Geographical Information Systems. The paper proposes flexible approaches to recommendation, for example, the development of decision support systems that embrace socio-economic, as well as, biophysical characterization, and field-testing of technology options as inputs into the model are critical for improved decision making.

TSBFI-Latin America

Published Work

Plant growth, biomass production and nutrient accumulation by slash/mulch agroforestry systems in tropical hillsides of Colombia

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Agroforestry Systems 60: 255-265 (2004)

Planted fallow systems under 'slash and mulch' management were compared with natural fallow systems at two farms (BM1 and BM2) in the Colombian Andes. The BM1 site was relatively more fertile than the BM2 site. Planted fallow systems evaluated included *Calliandra calothyrsus CIAT 20400* (CAL), *Indigofera constricta* (IND) or *Tithonia diversifola* (TTH). During each pruning event slashed biomass was weighed, surface-applied to the soil on the same plot and sub-samples taken for chemical analyses. While *Indigofera* trees consistently showed significantly greater ($p < 0.05$) plant height and collar diameter than *Calliandra* trees at both study sites, only collar diameter in *Indigofera* was significantly affected at all sampling times by differences between BM1 and BM2. After 27 months, TTH presented the greatest cumulative dry weight biomass (37 t ha^{-1}) and nutrient accumulation in biomass (417.5 kg N ha^{-1}, 85.3 kg P ha^{-1}, 928 kg K ha^{-1}, 299 kg Ca ha^{-1} and 127.6 kg Mg ha^{-1}) among planted fallow systems studied at BM1. Leaf biomass was significantly greater ($P < 0.05$) for CAL than IND irrespective of site. However, CAL and IND biomass from other plant parts studied and nutrient accumulation were generally similar at BM1 and BM2. At both sites, the natural fallow (NAT) consistently presented the lowest biomass production and nutrient accumulation among fallow systems. Planted fallows using *Calliandra* and *Indigofera* trees had the additional benefit of producing considerable quantities of firewood for household use.

2.2 Development of practices for managing BGBD indirectly through cropping system design and directly through inoculation strategies

TSBFI-Africa

On-going Work

Arbuscular Mycorrhizae dependency of different banana tissue culture cultivars
J. Jefwa and B. Vanlauwe

Arbuscular mycorrhizal fungi have potential to improve the performance of tissue cultured bananas in poor soils. The magnitude of response may vary between species and within species. Therefore, prior to establishment of tissue culture cultivars in poor soils, the response of different cultivars to different AMF isolates will be determined. A greenhouse experiment will be set up to determine dependency of different tissue culture cultivars on different AMF isolates. The objective of the current activity is to establish the effects of inoculation with different AMF isolates on the performance of different tissue culture banana cultivars. The treatment structure consists of 3 factors: (i) banana cultivar (10 cultivars – availability to be established –NARO and JKUAT), (ii) AMF isolates (2 isolates of *Glomus etunicatum, Glomus globiferum, Scutellospora cerradensis, Gigaspora margarita* and *Acualospora rehmii*/*A. scobiculata* and a control), and (iii) Inoculum (inoculum bulked in sand and inoculum bulked in nursery media). The parameters to be measured are: (i) measurements of aerial parts(height, length and diameter of pseudostem girth, leaf numbers and area measured weekly and the shoot fresh and dry weight measured at harvest), (ii) measurements of root morphological properties (root fresh and dry weight, root hair density and length, root length, AMF colonization measured at harvest), and (iii) measurements of plant nutrient levels (N, P, K, Ca, Mg, Zn to be measured at harvest). The experiment has started in October 2004 and is expected to last for about 5 months (2 months of bulking up the inoculum and 3 months of greenhouse experiment).

Develop strategies for demonstrating improved BGBD management and for establishing farmer experimentation

J.J. Ramisch, J. Huising (TSBF-CIAT)

The development or design of management practices for the conservation of BGBD is aimed to be done in collaboration with the farmer community, and requires farmer participation. Aspects of farmer participation and application of farmer participatory research (FPR) approaches are therefore considered to be part of developing strategies for demonstrating improved BGBD management. At the second annual meeting of the CSM-BGBD project, held in Embu Kenya, the working group (WG3) on sustainable management was established and introduced with a plan of action. WG3 deals with all the on-farm and community-based aspects of the project. As such it supports the activities of the other working groups by ensuring that the knowledge generated by the project can be translated into practical methods for land-users to conserve and manage BGBD through direct and indirect means to enhance sustainable production. The specific responsibilities of the WG3 in each country team include the following:

1. Identifying and managing stakeholder interactions. It is expected that the relevant stakeholders include not only the many institutions that come together as "country teams" but also national extension services, NGO's, and other community-based organisations such as farmer groups. Where community organisation is low or farmer groups absent, contact will need to be made with relevant local bodies to initiate and formalise grounds for project interaction with local communities.

In addition, it may be decided that country teams will need training and capacity building in participatory research methods as a means to improve the quality of interactions between stakeholders and the utility of the data collected.

2. Characterisation of existing land management practices and socio-economic characteristics that impact on BGBD. This characterisation includes:

- Collection and assessment of the contextual, secondary data (socio-economic, demographic, land-use, etc.) necessary for the site selection (in concert with WG2).
- The implementation and analysis of a baseline survey of existing management practices as they relate both to community and household characteristics.
- Using the baseline data, development of an appropriate household typology of farms / land-users, consistent with the land-use intensity index and other project-wide variables. This typology will assist in the inter-site comparison of practices and impacts, and also in the selection and involvement of land-users in the experimentation and demonstration phases.

3. Documenting and analysing local knowledge of below-ground biodiversity. Likely topics:

- Study and analysis of local indicators of soil quality or ecosystem change. Such indicators can help identify local priority areas for intervention and may also identify the existence of knowledge gaps that the project can fill.
- The role of local social networks or institutions (i.e.: tenure arrangements) in maintaining land-use management and sharing new knowledge.

4. The design and implementation of local experiments and / or demonstrations of improved management practices. In many ways this is the most important role for WG3. It integrates outputs from WG1 and WG2 (i.e.: to identify which technologies or approaches have greatest potential utility to smallholders and communities) as well as the knowledge generated by WG3 in the preceding three tasks.

- A major component of the on-farm experimentation and demonstration will certainly reflect each country team's attention to specific ecosystem services. Since such priorities are still being defined – from the ranking of community priorities and the research interests and abilities of the country teams, it is difficult to define in advance the scope and nature of the on-farm technology development. For example, experiments and demonstrations of rhizobial inoculation for better N fixation will demand different criteria for site and farmer selection than would those for improving decomposition processes, managing pests or disease, or improving water quality.
- There is also considerable opportunity under this activity to include networked experiments that are replicated across all seven countries. Such experiments are more likely to be researcher-led

since they will reflect priorities and topics that might be of only marginal interest to local communities.

5. Monitoring and evaluation (M&E) of project activities and progress. The discussion in Lampung showed that while the project proposal was not originally explicit in addressing M&E there is a need for the following types of monitoring / evaluation:

- Internal to the project, findings of the inventory WG1 in particular need to be regularly synthesised and their implications for management evaluated.
- Using the baseline surveys and the site selection criteria, changes in land-use and management within the study areas should be tracked and implications for BGBD and stakeholder involvement evaluated (will be in conjunction with WG4's Impact assessment group).
- Periodic stakeholder evaluation of project activities, including evaluation of changes in awareness and attitudes towards BGBD, implications of potential technologies, and recommendations emerging from the project.
- Participatory monitoring and evaluation by farmers and other land-users of the technologies being tested. This data collection is a fundamental part of the experimentation and demonstration, guiding the decisions to adapt or reject technologies.
- Synthesis of these M&E activities to feed into the project's reporting requirements (6-monthly reports on the objective and activity level of the log frame).

Capacity for socio-economic and participatory research varies between the project teams, which means that wherever feasible topics of local interest can (and should) be included. Thus a final task for WG3 is:

6. Identifying opportunities for useful synergy with local partners or projects (i.e.: existing on-farm experiments or demonstrations, NGO's with strong contacts to community organisations or sustainable agriculture activities). Topics of local importance, or which can capitalise on existing relationships are therefore much encouraged. This should also include collaborative use of existing socio-economic data sets and nationally relevant methodologies.

TSBFI-Latin America

Completed Work

Biological evaluation of the arable layer build-up in soils from the Colombian savannas

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Collaborative research jointly conducted by CIAT and Corpoica has shown that the physical, chemical and biological conditions of soils in the natural Colombian savannas are not suitable for agriculture. It is thus necessary to generate improved conditions for agriculture in these savanna soils by building an arable soil layer that can be cultivated. The purpose of this study was to assess the impact of two approaches to construct an arable layer on labile SOM fractions and soil N mineralization.

The Cultural Profile experiment was conducted in Matazul farm located in Puerto López (4° 9'49''N and 72° 38'23''W) in Meta department, Colombia. The experiment included three treatments with different chisel plow intensities (RAS1 = 1 pass, RAS2 = 2 passes, RAS3 = 3 passes), 3 agropastoral treatments namely: A+G = rice + *Andropogon gayanus*, A+L = Rice + Leguminosae (*Pueraria phaseoloides*+*Desmodium ovalifolium*), A+G+L = rice + *A. gayanus* + *P. phaseoloides* + *D.ovalifolium* and the control NS = native savanna almost exclusively composed of *Trachypogon vestitas*. The experiment had a randomized complete block design with 7 treatments and 3 reps. Experimental plots were 30 x 50 m and 20 soil samples (0-10 cm) were collected per plot to generate a composite sample. Size-density fractionation of SOM and aerobic and anaerobic N mineralization were conducted. Data for different parameters was analyzed using ANOVA and mean separation using the LSD test, and also treatment contrasts. Statistical significance refers to $P<0.05$.

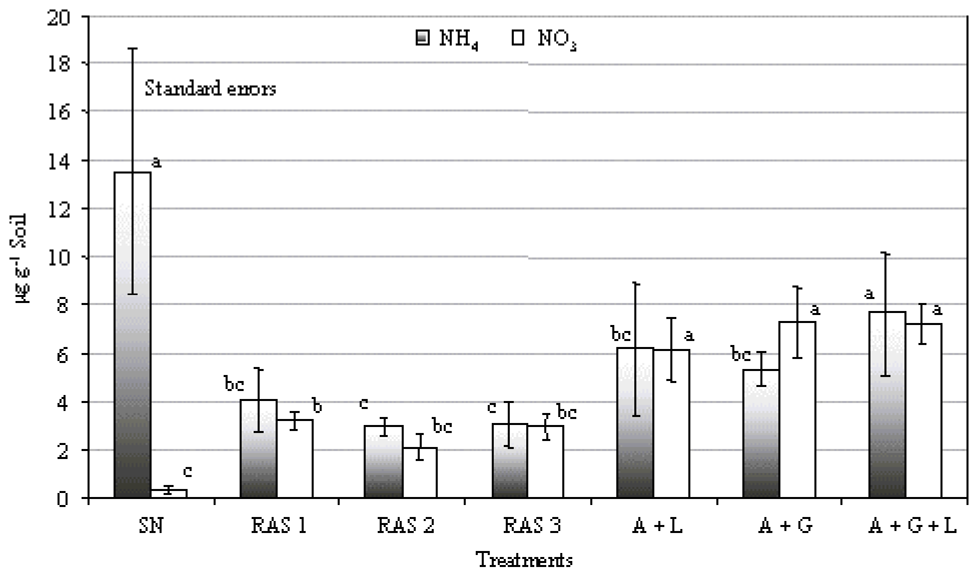

Figure 28. Soil inorganic N under different management systems used during arable layer build up in the Colombian Altillanura.* Means of treatments with the same letter does not differ statistically (*P< 0.05*).

Significant differences among treatments were only found in soil ammonium, nitrate and mineral N (Figure 28) but not in aerobic or anaerobic mineralization using lab incubations. Higher weight and lower N content in the LL (light) fraction of the native savanna and the opposite trend in other treatments was likely responsible for the lack of significant differences found in this usually sensitive parameter. These results are consistent with the literature showing that nitrification in tropical savannas is usually low so that accumulation of soil ammonium is a common phenomena.

Table 30. Contrasts test among soil management practices used for arable layer build up in the Colombian savannas.

Parameter	**Contrast**						
	Mean	**SN vs Others**		**Agp vs Lab**		**Gr vs Leg**	
Soil total Nitrogen (mg Kg^{-1} soil)	1334	135.4	ns	268.4	**	113.8	ns
Anaerobic N mineralization (µg g^{-1} soil d)	0.5	0.8	ns	0.6	*	0.3	ns
Aerobic N mineralization (µg g^{-1} soil d)	0.6	0.1	ns	0.2	ns	0.4	ns
Ammonium (µg g^{-1} soil)	6.1	8.6	**	3.1	*	-0.8	ns
Nitrate (µg g^{-1} soil)	4.2	-4.4	***	4.1	***	1.1	ns
Inorganic N (µg g^{-1} soil)	10.3	4.2	ns	7.2	***	0.3	ns
C amount in LL(mg g^{-1} fr)	376	40	***	12.3	*	-12.2	ns
N amount in LL (mg g^{-1} fr)	15.4	-3.4	**	-0.3	ns	-1.1	ns
C:N ratio in LL	24.7	9.5	***	1.3	ns	0.9	ns
N amount in LM (mg g^{-1} fr)	15.3	-1.8	**	0.8	ns	-2.4	**
Contributed N by LM(mg Kg^{-1} suelo)	5.3	-1.2	*	0.8	ns	-1.9	*
C:N ratio in LM	22.7	4.8	**	-0.9	ns	3.3	ns

Values correspond to the difference of means between contrasted treatment. *** p< 0.001, ** p< 0.01, * p< 0.05, ns = non significant. SN = Natural savanna, Gr = Grasses, Lab. = Tillage, Leg = Legumes, Agp. = Agro-pastoral

Treatment contrasts show that differences in native savanna were significantly higher for soil ammonium, LL-C concentration, and C/N ration in LL and LM, but significantly lower for soil nitrate, LL-C and N concentration, LM-N content in soil than other soil management systems studied. Treatment contrasts showed that agropastoral systems (A+G, A+L, A+G+L) had significantly higher soil total N, ammonium, nitrate and inorganic N, aerobic N mineralization and LL-C concentration when compared with tillage systems (RAS1, RAS2, RAS3). These results suggest that N input by the legume component was important in contributing to higher N stocks and availability in agropastoral systems. Agropastoral systems containing only grasses had significantly lower LM-N concentration and LL-N content in soil than those systems including legumes (Table 30). This further confirms the important role of legumes in improving SOM quality with higher N inputs that promote soil N mineralization and availability. When grass systems alone were compared with those containing legumes they had significantly higher soil ammonium but lower soil nitrate. The use of legumes during arable layer build up was shown to be important to increase soil N status and presumably also the biological activity although not directly shown in this study.

2.3 Management options to enhance soil-based ecosystem services, with an initial focus on the long-term impacts of organic and inorganic resource management, developed and tested

TSBFI-Africa

Published Work

***Senna siamea* trees recycle Ca from a Ca-rich subsoil and increase the topsoil pH in agroforestry systems in the West African derived savanna zone**

B Vanlauwe, K Aihou, B K Tossah, J Diels, N Sanginga and R Merckx

Plant and Soil, 2004, In Press

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*, *Gliridia*, 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.

Long-term integrated soil fertility management in South-western Nigeria: crop performance and impact on the soil fertility status

B. Vanlauwe, J Diels, N Sanginga and R. Merckx

Plant and Soil, 2004, In Press

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, most of it ascribed to tree die-off, but more drastically for *Leucaena* than for *Senna*. In 2002, the nitrogen contribution from *Leucaena* residues stabilized at about 200 kg N/ha, while the corresponding value for *Senna* was about 160kg N/ha. Over the four pruning events per year, the relative contributions of each pruning were different for the two tree species. 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 over the 16 years studied, but the least so in the *Senna* + fertilizer treatment where in 2002 still 2.2 tonnes/ha of maize were obtained. The fertilizer only treatment led to a yield of only 0.4 tonnes in 2002, the absolute control without any inputs yielded a mere 40kg/ha in the same year. Cowpea yields were rarely significantly affected by the treatments and more affected by disease and/or drought than by the imposed soil fertility treatments. Nitrogen fertilizer use efficiency was usually higher in the *Senna* treatment compared to the control or the *Leucaena* treatment. Interactions between fertilizer and organic matter additions were negative for the *Leucaena* treatments in the first three years, and were positive for the *Senna* treatment in the last 6 years. At all other times, there was no interaction. Most chemical soil fertility parameters decreased in all the treatments, but this was less so in the tree-based alley cropping systems. The presence of trees had a positive effect on 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. Soil pH_{KCl} values decreased with at least 0.5 units in the control and *Leucaena* treatments, but only slightly in the *Senna* treatments. In general, the soils that received fertilizer during the trial were more acid (0.2 to 0.3 units) than the ones not receiving fertilizer. 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 a positive interaction between fertilizer nitrogen and organic residue treatment and in a more stable maize yield over the years, averaging 2.8 tonnes/ha with maximal deviations from the average not exceeding 21%.

Long-term effect of tillage and manure application on soil carbon dynamics, soil biological activity and crop performance under Sudano-Sahelian conditions
Mando, A., B. Ouattara, M. Sédogo, L. Stroosnijder , K. Ouattara, L. Brussaard and B. Vanlauwe
Soil Use and Management, 2004, In Press
Human-induced degradation of natural resources in general and of soil in particular, is a major problem in Sudano-Sahelian zones. In order to find efficient soil management practices that maintain or improve soil fertility, research was conducted at Saria research station in the centre of Burkina Faso (12º 16' N, 2º 9' W). The combined effect of tillage and manure application on Lixisol properties and on crop performance were studied. A randomised 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 carbon, different fractions of soil organic matter (SOM), microbial biomass and CO_2 production were measured. Over the 10-year period, carbon content had dropped from 400 to 205 mg/100g soil in ploughed plots without manure and from 400 to 250 mg/100g soil in hoed plots without manure. Manure addition mitigated the decrease of SOM in ploughed plots and even built up SOM in hoed plots, where it increased from 400 to 580 mg/100g soil. Manure had a large effect on the fractions in which SOM is stored. In ploughed plots, a large amount of SOM is stored in physical particles > 0.250 mm, while in unploughed plots the maximum SOM is stored in finer fractions. In the topsoil, hoeing and manure resulted in a higher SOM than ploughing with no manure. However, in the 15–25 cm layer, particularly in September, there was more particulate organic matter (POM) in ploughed plots with manure than in hoed plots with manure. The SOM decomposition rate was 17 % less on the ploughed plots without manure than on hand-hoed plots without manure. CO_2 production was higher and quicker for hoed plots with manure than for ploughed 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 soil carbon and related properties and therefore can contribute to the sustainability of the agricultural system in the Sudano-Sahelian zone. Furthermore, ploughing with manure has the most significant impact on yields and has little effect on soil carbon except for a slight loss in the topsoil and a slight accumulation in deeper layers and therefore should be promoted in the region.

Long-term effects of inorganic and organic fertilization on soil organic matter fractions, sorghum yield and fertilizer-N recovery under sudano-Sahelian conditions

Mando, A., Bonzi, M., Wopereis, M.C.S., Lompo, F., Fofana, B., Vanlauwe, B., Stroosnijder L., Breman, H

Soil and Tillage Research, 2004, In Press

Knowledge of changes in soil organic matter fractions resulting from agricultural practices is important to assess their sustainability. A long-term trial sited in Burkina Faso under semi-arid, sudano-sahelian conditions and initiated in 1980 was used to assess the effect of organic and inorganic fertilization on soil organic matter fractions, sorghum yield and inorganic fertilizer-N recovery. During 22 years, 11 treatments were tested with 6 replications. Organic fertilizers (i.e. sorghum straw, kraal manure and aerobic and anaerobic compost) were applied yearly at 10 t ha^{-1}, with and without 60 kg of urea N ha^{-1}. The remaining three treatments included a control (no fertilization), only inorganic fertilization (60 kg N ha^{-1}) and fallowing. Fallow plots had significantly higher SOM and N levels over all other treatments. SOM and N concentrations increased in the following order: only urea application < straw < control < straw + urea < anaerobic and aerobic compost with or without urea < manure with or without urea < fallow. Taking land out of fallow had an adverse effect on SOM and soil organic nitrogen status, however this mostly affected the fraction of SOM > 0.053mm (particulate organic matter, POM). The POM concentrations in the control, straw and urea-only plots were about half of the POM concentrations in the fallow plots. POM concentrations increased in the following order: urea < control < straw with or without urea < aerobic or anaerobic compost with or without urea < manure with or without urea < fallow. The fraction of SOM < 0.053mm (fine organic matter, FOM) was greater than POM in all plots except in fallow and (manure + urea) plots. Total nitrogen concentration followed the same trend as soil organic matter, but cultivation led to a decline in both N-POM and N-FOM. Crop yield and nutrient uptake were greatest in the manure plots and lowest in the straw, control and urea only plots. Urea-N recovery was 53% in manure plots, 40% in straw plots and 10% in control plots. Results indicate that under the semi-arid conditions of the experiment, SOM status, POM and FOM fractions, crop yields, nutrient uptake and fertilizer recovery were better sustained using organic resources with a low C/N ratio (manure) than through organic resources with a relatively high C/N ratio (straw). Urea improved the effect of the organic resources with high C/N ratio, particularly in case of straw application. Skilled use of available organic resources combined with judicious use of mineral fertilizers is key to sustainable agriculture in the Sudano-Sahelian zone.

On-going work of AfNet

On-farm evaluation of soil fertility restoration technologies

<u>Site 1: Karabedji and Gaya</u>

Past research results indicated a very attractive technology consisting of hill placement of small quantities of P fertilizers. With DAP containing 46% P2O5 and a compound NPK fertilizer (15-15-15) containing only 15% P2O5, fields trials were carried out by farmers on 56 plot per treatment to compare the economic advantage of the two sources of P for millet production. As hill placement can result in soil P mining another treatment was added consisting of application of phosphate rock at 13 kg P/ha plus hill placement of 4 kg P/ha as NPK compound fertilizers.

The data in Table 31 clearly shows that there was no difference between hill placement of DAP and 15-15-15 indicating that with the low cost per unit of P associated with DAP, this source of fertilizer should be recommended to farmers. The basal application of Tahoua Phosphate rock gave about additional 300 kg/ha of pearl millet grain.

Table 31. Farmers managed trials at Karabedji and Gaya, 2003 rainy season.

	Millet grain yield (kg/ha)		Millet TDM yield (kg/ha)	
Treatments	**Karabedji**	**Gaya**	**Karabedji**	**Gaya**
1=farmers' practices	252	319	1709	1826
2=NPK HP	714	559	2766	2563
3=DAP HP	699	752	2771	3125
4=PRT+NPK HP	921	997	3274	3838
SE	8	23	13	64
CV	10%	26%	4%	16%

NPK: 15-15-15 compound fertilizers
DAP: Diammonium phosphate
HP: hill placement at 4 kg P/ha
PRT: Tahoua Phosphate rock broadcast at 13 kg P/ha

The combination of hill placement of water-soluble P fertilizer with phosphate rock seems a very attractive option for the resource poor farmers in this region. The data in Figures 29&30 is showing the variation of yield of each plot in farmers fields as compared to the farmer's practices and clearly shows that the application of Tahoua PR with hill placement of water soluble P outperformed the other treatments in most instances.

At Gaya, the same effect can be observed and DAP seem better than NPK and confirm the choice on this source (Table 31).

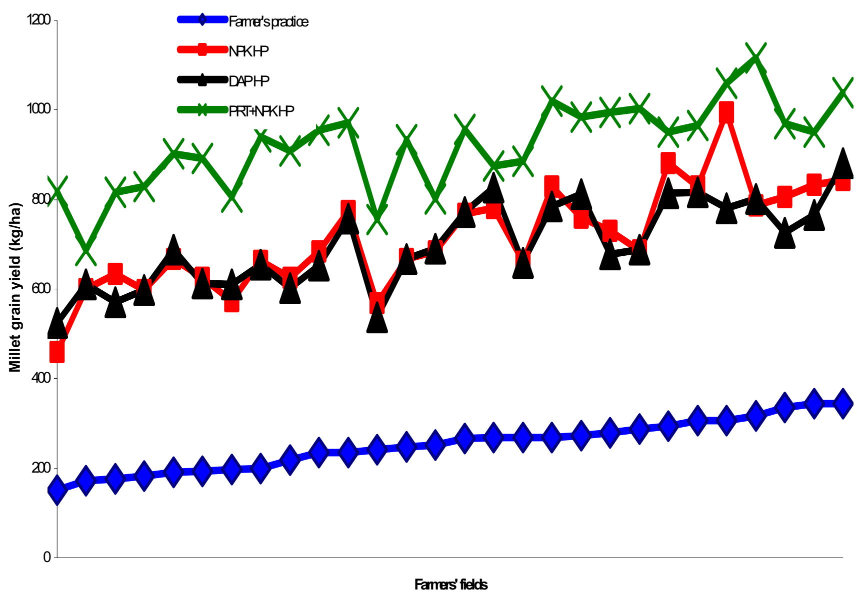

Figure 29. Millet grain yield response to different management practices, Karabedji, Niger, 2003 rainy season

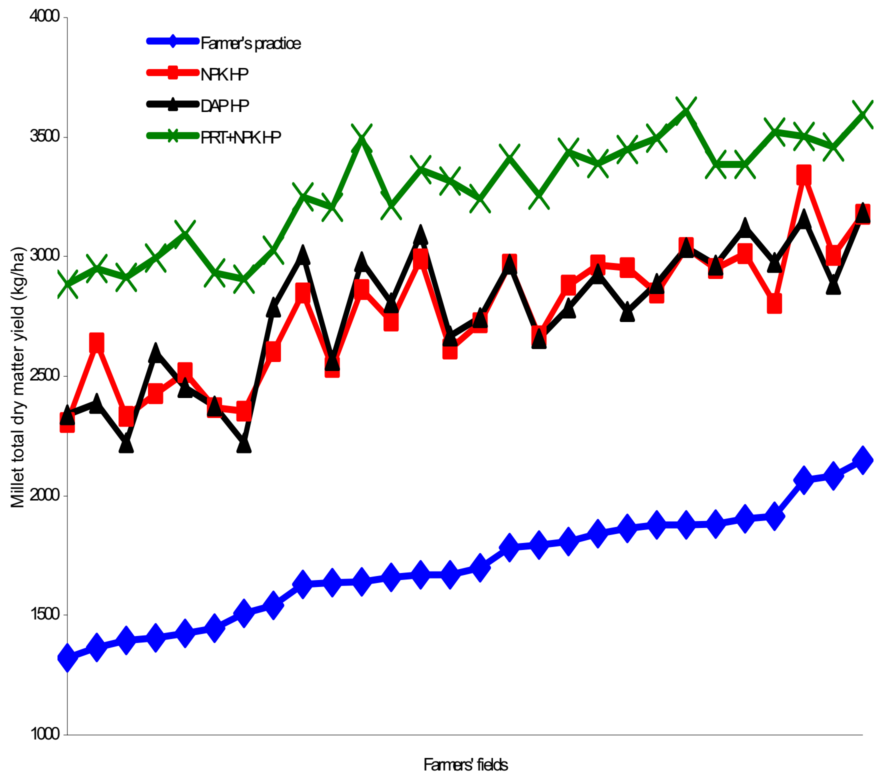

Figure 30. Millet total dry matter yield response to different management practices, Karabedji, Niger, 2003 rainy season

Site 2: Kenya

On-farm evaluation and scaling-up of soil fertility management technologies in western Kenya

On-farm trials were conducted during 2002-2004 cropping seasons in two village clusters in Tiriki West and Kabras Divisions in Vihiga and Kakamega Districts, respectively. Farmers were involved in selection of treatments, monitoring and evaluation of the trials. Prior to setting up the trials, relevant technologies were exposed to farmers by researchers and extension agents. The farmers selected maize as the test crop and the following treatments by consensus: 5 tha^{-1} FYM (Farm Yard Manure); 60 P2O5 kg ha^{-1} & 60 N kg ha^{-1} (inorganic fertilisers); 2.5 t ha^{-1} FYM & 30 P2O5 kg ha^{-1} (inorganic fertilisers); and farmers' practice, which varied from farm to farm. Field days were organised to expose many farmers to the technologies and obtain their perceptions. Data were analysed by conventional economics techniques and through farmer evaluations. Results show that farmers did not necessarily choose technologies with highest agronomic and/or economic performance (60 P2O5 & 60 N kg ha^{-1}). About 75% of the farmers preferred 30 kg ha^{-1} P2O5 + 2.5 tha^{-1} FYM, despite not generating the highest yield and economic returns, but because they perceived that they could afford or access the requisite inputs.

Completed Work

Emissions of greenhouse gases in an intensive dairy farm in Rozo Colombia

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Cattle are responsible for important direct emissions of methane to the atmosphere. There are also appreciable fluxes of greenhouse gases (GHG) involved in the process of producing the forage consumed by the animals as well as on the disposal of the animal manure. It has been proposed that intensive operations based on controlled balanced diets could result in a net decrease in net emissions of methane per unit of final product (meat or milk), compared to traditional extensive or even intensive grazing systems. However there are very few studies comparing intensive versus extensive systems regarding net emissions of greenhouse gases associated with cattle.

A study was conducted at the Pasoancho dairy farm located near the village of Rozo in Colombia. to assess net emissions of GHG associated with the production of feed for confined dairy cows and the fluxes resulting from the disposal of animal manures in an intensive dairy farm operating a cut and carry system. The study was conducted Annual rainfall is 800 mm and average temperature is 26.8°C. The farm maintains a herd of around 920 confined cows and produces 10,500 liters of milk per day from 570 lactating cows. Forages used in the system are produced in 230 hectares of intensively cultivated land. Cut and carry forages include alfalfa (*Medigaco sativa*), Sorghum (*Sorghum bicolor*) and Guinea grass (*Panicum maximum*). The farm also has 26 ha of a silvopastoral system integrating guinea grass and tress of *Psamanea saman,* where 4 heads.ha^{-1} of grazing cows are maintained. The farm has operated with this system for about ten years and forage production has been managed as monocropping. The farm produces a large amount of animal manure (12.8 Mg. $head^{-1}.y^{-1}$) that is spread using a special tool on top of the pastureland. The soil is a typic vertisol of loamy texture with neutral pH and high levels of available nutrients. Alfalfa has a cycle of 28 days from seeding to harvest while the sorghum cycle is 56 days. The guinea grass is cut at around one month intervals.

To assess net fluxes of GHG in the cut and carry system, various components were measured: fluxes from the land used to produce the forages; fluxes from the animal excreta during the time that they stay in the stable and fluxes resulting from the application of untreated animal manures to the forage land. Methane emissions from the enteric fermentation were estimated using factors from tropical regions (IPCC, 2001). Fluxes from a silvopastoral system on the same farm were also measured. The vented chamber methodology was used in all cases. Fluxes from the soil were monitored over a six month period. Fluxes from animal untreated excreta were monitored intensively over a 20-day period. One of the grass plots that is regularly spread with the manure was selected. A section of the plot (20 m x 20 m) was used as a control with no application of the manure. Fluxes on the manure in the stable were intensively monitored over a three-day period. Gas samples were collected in pre-evacuated glass vials and were analyzed within a week by ECD-FID gas Chromatography.

Net release of methane and nitrous oxide from the animal excreta at the stable is very high at 1200 mg $m^{-2}d^{-1}$ and 70 mg $m^{-2}d^{-1}$ respectively, likely as a result of prevalence of anaerobic condition which favor methanogenesis and denitrification processes. Residence time of the excreta is around 1 day in the stable and due to this short residence time the contribution of emission in the stable to total emissions is not very significant. The application of untreated animal excreta to the fields result in net equivalent emissions of 472.8 mg CH_4 m^{-2} and 64.3 mg N_2O m^{-2} per application event (excreta is applied at a total rate of 50 Mg $ha^{-1}y^{-1}$, split in 6 applications). As can be seen in figure 31, essentially all the methane is released within the two initial days after application, while the nitrous oxide is released in the initial week. Methane dominates total emissions of GHG from the manure, however given the high warming potential of N_2O as compared to CH_4 (around 12 times higher), nitrous oxide emission from the manure can not be neglected.

In Table 32, values are shown for the area under different livestock production systems in the farm as well as net fluxes for of methane and nitrous oxide measured between the soil and the atmosphere. Guinea grass receiving fresh applications of manure showed the highest emissions of methane at 306.5 kg CH_4 $year^{-1}$, followed by emissions from the silvopastoral grazing plots. Both plots received applications of fresh animal manure and this input is responsible for most of net emissions of both gases. The plots on alfalfa and sorghum are net sinks of atmospheric methane, but cannot counterbalance net emissions from the manured plots, and at the farm level emissions from applied manure account for most of the methane balance. Rates of N_2O emissions were higher in the plots receiving manure application. These plots also received additional applications of 80 kg N.ha^{-1} while alfalfa received 40 kg N.ha^{-1} and sorghum 60 kg N.ha^{-1}. Due to their large area cover, plots with sorghum account for the majority of the emissions of nitrous oxide (689.3 kg N_2O $year^{-1}$) at the farm level.

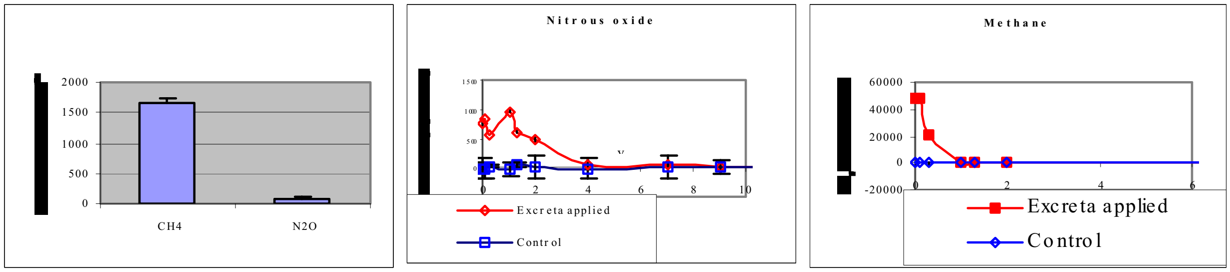

Figure 31. Emissions of methane and nitrous oxide resulting from one event application of animal untreated manure to pasture plots. Rate was equivalent to 8 Mg fresh manure ha^{-1}. Fluxes were monitored over a 20 day period.

Estimation of fluxes of methane from enteric fermentation were based on factors proposed by the IPCC. The same factor was used for both production systems. Total annual methane emission from confined feeding cattle was estimated at 52.4 Mg CH_4 y^{-1}. Corresponding flux for the grazing cows was calculated as 2.96 Mg CH_4 y^{-1}. At the farm level, total fluxes of methane are dominated by emissions by cattle totaling 99% of methane emissions.

In Table 33, the net global warming potential (GWP) resulting from the emissions of methane and nitrous oxide for the silvopastoral and confined feeding systems including methane emissions by enteric fermentation, are presented in units of kg of CO_2 equivalents. Data for milk production in the two systems is also reported. The silvopastoral system supports a stocking rate of 4 heads per ha with a rotation period of 20 days and 20 of resting, which results in an effective stocking rate of 2 head ha^{-1} over the year.

Table 32. Annual fluxes of methane and nitrous oxide from soils under two production systems.

Forage	Total area	Emission rate: $kg.ha^{-1}.y^{-1}$		Farm emissions: $kg.y^{-1}$	
		Methane	**Nitrous oxide**	**Methane**	**Nitrous oxide**
Silvopastoral*	26	11.5	7.1	299.3 (45)	195 (38)
Confined feeding					
Alfalfa	10	-0.662	1.91	-6.62 (1.5)	19.1 (4.4)
Sorghum	180	-0.311	3.83	-55.9 (6.9)	689.2 (134)
Guinea Grass *	16	22.5	5.6	360.1 (54)	96 (29)
Total Confined feeding	206			297.4 (52)	804.3 (152)

Animal excreta applied at an annual rate of 50 Mg. ha^{-1} .Number in parenthesis represent standard deviation.

Data on Table 33 supports the hypothesis that intensive confined feeding livestock systems could result in lower emission rates of greenhouse gases per unit of product as compared to grazing systems. Given that total emissions are controlled by the cattle contribution, it is necessary to generate measurements to assess the effect of the two types of diets in the farm on measured emissions from the enteric fermentation. An attempt will be made to obtain this information using a Rusitec in vitro rumen simulation methodology. Results from a parallel study (data not reported here) measuring net fluxes of methane and nitrous oxide from animal manure being stabilized before application to the grass plots, indicated that total emissions of the two gases could be reduced to less than half by the aerobic stabilization procedure, therefore recommendations have been provided to farm managers to adopt processing of the animal excreta before spreading it to the fields.

Table 33. Global warming potential from the production systems: grazing vs. confined feeding at the Pasoancho dairy farm. Colombia.

System	GWP in Mg CO_2 equivalents. y^{-1}			Milk production $ML.y^{-1}$	GWP per unit product. kg $CO_{2\ equivalents}$.L milk $^{-1}$
	CH_4	N_2O	Total		
Confined feeding	1213	267	1479	3.83	0.386
Silvopastoral	75	55	130	0.20	0.655

2.4 Innovations for managing erosion and soil biophysical conditions/constraints developed and tested (e.g. conservation tillage, arable layer, water harvesting, organic matter build-up, etc.)

TSBFI-Africa

On-going Work

This work is being conducted by a Masters student registered at Makerere University, Uganda to investigate the on-farm comparison of the economic profitability of selected dual purpose live barrier in hilly ecosystem. The objectives of the study are:

1. To assess the effectiveness of selected dual-purpose live barrier system in soil conservation;
2. To the profitability the selected dual purpose, live barrier used soil conservation; and
3. Determine nutrient loss through the established live barrier.

Accelerated soil erosion poses a serious threat to agriculture in highland farming systems through increasing soil fertility loss. Live barriers are considered to be a potential option for soil and water conservation in highland ecosystems. However, adoption of such technologies is low because most farmers do not see a demonstrated, economic benefit, for adopting such technologies and because the benefits of soil and water conservation alone don't repay the investment in labor and land. Farmers selected four multi-purpose live barrier systems (Calliandra, Napier, Setaria, and sugarcane and were evaluated under the same experimental conditions to identify the most efficient and economic live barrier system in soil and nutrient loss reduction, income generation and returns to investment. Setaria grass, followed by sugarcane was the most efficient in soil erosion reduction in the three cropping seasons compared to Napier and Calliandra. This was mainly because Setaria and Sugarcane had a high number of dense tillers compared to Napier which had widely spaced tillers. Napier grass was the most economically viable and profitable option because of its high yield of fodder which was sold, followed by Sugarcane. This work will be continued to allow comparison of the slower growing Calliandra over more seasons.

TSBFI-Latin America

Published Work

Use of deep-rooted tropical pastures to build-up an arable layer through improved soil properties of an Oxisol in the Eastern Plains (Llanos Orientales) of Colombia

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Agriculture, Ecosystems and Environment 103: 269-277 (2004).

It is widely believed that tropical soils (mainly Oxisols) have excellent physical characteristics such as high infiltration rates, high permeability of water, good and stable soil structure and that consequently, they can support mechanized agriculture. However in the Eastern Plains (Llanos Orientales) of Colombia, when Oxisols are subjected to tillage using disc harrow, soil physical conditions deteriorate rapidly. We report here that change in land use with deep-rooted tropical pastures can enhance soil quality by improving the size and stability of soil aggregates when compared with soils under monocropping. In addition, rates of water infiltration improved by 5 to 10-fold while rainfall acceptance capacity improved by 3 to 5-fold. We suggest that intensive and sustainable use of these Oxisols, could only be possible if an "arable" or "productive layer" (i.e. a layer with improved soil physical, chemical and biological properties) is constructed and maintained. One option to achieve this arable layer is through the use of introduced tropical pastures with deep rooting abilities that can result in increased soil organic matter and associated improvements in soil physical, chemical and biological properties. One land use option that can achieve these soil improvements is agropastoralism whereby pastures and crops are grown in short-term rotations.

Development of an arable layer: A key concept for better management of infertile tropical savanna soils

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In: A. Bationo, J. Kimetu and J. Kihara (eds). International Symposium of the African Network for Soil Biology and Fertility (AfNet) of TSBF Institute of CIAT. Improving Human Welfare and Enfironmental Conservation by Empowering Farmers to Combat Soil Fertility Degradation. Yaoundé, Cameroon, May 17-21, 2004. pp. 112-113.
A concept that is highly relevant for the better management of infertile tropical savanna soils is that of the buildup of an arable layer". Before tropical savanna soils can be used for no-tillage systems, the soil's quality in terms of physical, chemical and biological characteristics need to be improved. The application of this concept will depend on the prevailing soil constraints and current land use, for example, soil compaction and loss of soil structure versus depletion of soil nutrients and the type of crops to be cultivated. The concept includes tillage practices to overcome physical constraints, an efficient use of amendments and fertilizers to correct chemical constraints and imbalances, and the use of improved tropical forage grasses, green manures and other organic matter inputs such as crop residues, to improve the soil "bio-structure" and biological activity. The use of deep-rooting plants in rotational systems to recover water and nutrients from subsoil is also envisaged in this scheme. This concept builds on earlier suggestions for the better management of tropical soils. To be functional, however, more attention needs to be given to the driving forces behind farmer decision making and the existing policies for intensifying agriculture on infertile savanna lands.

Physico-chemical conditions of a soil under different treatments and their effect on yields, weed populations and root development in direct planting in the Colombian Plains

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Tropical Soil Biology and Fertility (TSBF) Institute of CIAT
In 1993 a trial, referred as Culticore, was established in Carimagua, Meta Province, Colombia. The purpose was to develop sustainable production systems in the Oxisols of the Eastern Plains. In Phase I (1993-1998) soil management practices were implemented leading to improvement of the soil through liming, fertilization and implementation of crop rotation systems: fundamentally rice-cowpeas, maize-soybeans, and grass alone or with legumes in plots of 18 x 200 m, with 4 replications. In 1999 the trial was split in two, leaving plots of 18 x 100 m for Phase II, in which the objective was to determine whether the improvement obtained in Phase I was sufficient to support or not direct planting. Rotational systems of rice-soybeans and maize-soybeans were established along the plots, using tillage with a chisel or not, and planted directly with a seed drill. This work was done in a well-drained, clay-silty Oxisol (tropeptic haplustox, isohyperthermic) with low fertility, pH 4.5, low exchange values of Ca, Mg and K, an Al saturation of more than 90%, and an annual average rainfall and temperature of 2280 mm and 26^{o}C, respectively. Samples were taken for yield in rice and maize, for botanical composition to evaluate

undesirable plants and for roots evaluation in the crop's flowering stage. Significant differences were found among treatments and tillage. In 2000 the highest maize yields were obtained in T10 (pasture of *Panicum maximum* + legumes) with an average production of 4178 kg/ha. In 2001, 4191 kg/ha were recorded in T8 (maize-soybeans green manure). Maize yield under tillage with the chisel was better in 2001 than in 2000; whereas with zero tillage, the yields decreased with respect to the previous year. In rice it was observed that the average yield for 2001 was lower than that obtained the previous year, where the highest production was in Treatment 10 (pasture of *P. maximum* + legumes) with 3604 kg/ha; while in 2001 it was in Treatment 3 (rice-cowpeas green manure) with 2797 kg/ha. In general all treatments were affected, to a greater or lesser extent, by the presence of undesirable species; thus there were low correlations between weed coverage and yields. In the case of species such as *Digitaria horizontalis*, *Borreria capitata*, *Emilia sonchifolia*, *Mimosa pudica* and *Croton trinitatis*, there were negative correlations, which indicates that grain yields will diminish to the extent that these species increase. There was a high correlation (r^2=0.72) between root development and yields.

The effect of improving soil properties on productivity in two soils of the flat savannas in the Province of Meta, Colombia

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Oxisols represent 57% of the Colombian national territory, of which almost 17 million hectares belong to the savannas in the Eastern Plains. Within this region flat savannas account for 3.4 million hectares. These soils are characterized by low pH values (4.0-4.8), high Al saturation (> 90%), and low levels of nutrients (P, K, Ca and Mg) available for the plants—all factors that limit the production of this zone. The susceptibility of these soils to degradation and the loss of productivity when they are submitted to agriculture and/or livestock production is the principal constraint for commercial-scale and sustainable use. Low-depth tillage done with a disk harrow has caused problems of a physical nature, such as surface sealing and crusting, high bulk density, compaction, low infiltration rates, low rainfall acceptance, high susceptibility to erosion in recently prepared soils, and high runoff. To overcome these problems, the concept of constructing an arable layer was proposed, defined in this context as a surface layer of soil, planned and developed by man, with minimum physical, chemical and biological constraints in order to guarantee stable crop yields, sustainable over time. This study proposed the construction of productive arable layers in two soil textures in a three-year period, using a rigid chisel for tillage and different strategies of soil improvement, seeking to accomplish: (1) vertical loosening of the soil to achieve greater infiltration of water in the soil for a more homogeneous distribution of amendments and nutrients in the profile of improvement and (2) physical stability to the post-tillage soil through the use of materials with high root production to maintain the favorable conditions obtained with the vertical tillage. By the third year of improvement, there were two- to five-fold increases in the infiltration rates of water in the soil, 13-21% increases in total porosity, 60-80% reductions in the resistance to root penetration, 50-65% decreases in horizontal tangential resistance to root expansion, and a 10-15% decrease in compaction of the soil. As a result of the integrated improvement of the soil, the yields of crops adapted to the zone increased the second to third year of soil improvement. It was then possible to plant high-yielding maize materials, which had high levels of production in comparison to the adapted ones.

Completed Work

Strategies for constructing productive arable layers in two texture soils of the Colombian savannas

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A special project financed by PRONATTA from 2001 to 2003 was completed this year. From 1996 to 1999 a diagnosis made on the impact that time of use of the soil had have in their characteristics, entitled "*Impact of different uses and management of soil in the chemical, physical and biological conditions*" and conducted by CIAT-CORPOICA and UNILLANOS, showed that several negative changes had occurred over time. The results of this project, together with other long-term experiments, clearly indicated that the management given to these soils had led them to structural degradation and loss of productivity. Significant losses in organic matter and decrease in macroaggregates in comparison with undisturbed savannas in a wide range of textures were found. These effects, produced soil sealing, which was reflected in high levels of soil hardness, compaction and fall of water infiltration. As a consequence, of the use of harrows, more than 70% of the lime and nutrients applied, were concentrated in the top first 0-5 cm of soil depth in all land uses. As a solution to this problem, the construction of a productive "arable layer" in two textural soils, over a three-year period was proposed, using plow chisels as the basic tool for tillage at two depths: 0-30 and 0-45 cm, with the following proposes: (1) to increase water infiltration and water storage capacity and to get a more homogeneous distribution of lime and nutrients in the chiseled soil depth, and (2) to obtain a better physical stabilization of the tilled soil by promoting rooting of already adapted genetic plant materials to plantain the favorable conditions accomplished by the vertical tillage.

The following are main conclusions from this project:

Chemical improvement of the soil

1. In the two soil textures, light and heavy, the goals for calcium saturation (50 and 40%) and magnesium saturation (20 and 16%) in the first 0-15 cm of the profile were reached.
2. The goals for calcium (1.5 cmol/kg)) and magnesium content (0.6 cmol/kg) in the first 0-15 cm of the profile were reached in the heavy texture but not in the light one, which was reflected in less crop yields.
3. The goals for phosphorus content of 10 and 8 ppm for light and heavy textures, respectively, were higher in all cases.
4. The models generated to correct acidity and leave acceptable levels of calcium and magnesium in the soil for sustainable agricultural production were estimated at 5200 and 6500 kg of dolomitic lime per hectare (distributed over two years) for light and heavy textures, respectively.
5. At 15-25 cm in depth the calcium content continued to be limiting in the two soil textures, reaching levels from 0.15 to 0.24 cmol/kg with Al saturations of 65 and 79% for the light and heavy textures, respectively.
6. Soil nutrition capacity in the subsoil can be improved by applying calcium and magnesium sulfates, which help lower the bases in the profile when the physical conditions of the soil have improved.
7. A tillage depth of 0-45 cm produced a higher level of chemical improvement of the soil in all cases, with lower levels of Al saturation at all depths.
8. The crop systems including pastures and legumes, showed better chemical improvement that the annual crops system.

Organic improvement of the soil

9. The light texture showed increases in organic matter until 35 cm of the soil profile at both tillage depths; while in the heavy texture this increased to a tillage depth of 0-30 cm.
10. In general the tillage treatments conserved or increased the organic matter content of the soil. Greater increases of organic matter are expected in the future as these soils will not be subjected to further tillage activities. They will be cultivated under no-tillage system.

Physical improvement of the soil

11. In relation to native savanna, greater infiltrations of water were obtained at a tillage depth of 0-30 cm in the light-textured soil and 0-45 cm in the heavy texture, possibly associated with better root distribution.
12. Besides of improvement of infiltration rates (two to five-fold increase) at the third year there were 13-21% increases in total porosity, 60-80% reductions in penetrability, 50-65% decreases in soil strength, and a 10-15% decrease in the susceptivility to compaction.

13. A better pore size distribution was obtained in the two soil textures. The two tillage depths, maintaining or decreasing the micropores and significant increased the mesopores and, to a lesser extent, macropores, favoring processes of water storage and soil aeration.
14. Highly significant ($P<0.001$) correlations were found between the variables resistance to penetrability and soil strength ($r=0.97$), between soil strength and root density ($r=-0.72$); between root density and percent of organic matter ($r=0.83$), and between organic matter and bulk density ($r= -0.92$).
15. The available water in the light soil was exhausted after 3-4 days of drought; but by the second day, the plants were stressed. In the heavier soil water was exhausted in 7-8 days.
16. A pressure of 11.7 kg/cm^2 was considered as a critical level for penetrability. The area affected by the compaction was estimated at 6.3%.

Biological improvement of the soil

17. Decreases in the populations of *Actinomyces* and fungi occured in all the treatments, possibly as a result of changes in the quality of the organic matter of the soil in the case of *Actinomyces* and for an increases of pH in the case of the fungi. It also could be due, to an improvement of soil aeration.
18. Although the bacterial populations tended to increase, they continued to be marginal. The question that remains is whether the soils have few bacteria or the current methodologies of counting in the petri dishes are not reliable.
19. After the maize harvest in the third year, high populations of VAM were found with high percentages of infection, the populations being significantly higher in the heavy-textured soils at all the depths of the profile.
20. The biodiversity of the VAM species increased with the soil improvement, going from six species in savanna soils to 15 and 16 species in improved soils at depths of 0-30 and 0-45 cm, respectively.
21. The biodiversity of species of fungi increased with the soil improvement, going from three species in savanna soils to six species for the two depths of soil improvement.

Improvement in productivity

22. The *B. brizantha* (cv. Toledo) grass showed increases in forage biomass equivalent to 1-2 t/ha when lime+Sulcamag were used as amendments and greater tillage depth used.
23. The rice and millet showed no response, in grain yield, to Sulcamag or tillage depth, given that these materials are better adapted to the conditions of acidity of these soils.
24. Soybeans gave greater grain yields with Sulcamag and depth of tillage in both textures; however, the response was greater in aerial biomass, height and greenness, which suggest that other cultivars with greater genetic potential could be used.
25. Maize H-108 showed positive responses in grain yields to Sulcamag and tillage depth, in the second year of soil improvement. Yields increased from the second to the third year of soil improvement, from 3789 to 4560 kg/ha in the light texture and from 4306 to 4703 in the heavy-textured soil.
26. When the change was made from maize H-108 to an HYM (high yield maize) in the third year, the yields increased from 4560 to 5375 kg/ha in the light-textured soil and from 4703 to 6196 kg/ha in the heavy texture.

Improvement in profitability

27. The two technological options presented [(1) soil improvement at 0-30 cm depth and use of dolomitic lime with regional crops and (2) soil improvement at 0-45 cm depth with the use of lime+Sulcamag and HYM, showed high profitability, with return internal rates of 30 and 33% respectively.

Environmental improvement

28. Indicators of environmental improvement are presented in terms of conservation, increase of soil organic matter quality, increases in the biodiversity of fungi and VAM, decrease in hardness both vertically and horizontally, greater porosity and infiltration of water in the soil that help to prevent erosion, loss of nutrients by runoff and contamination of waters.

2.5 Socio-economic and policy constraints to the adoption of ISFM options identified and potential solutions tested.

2.6 Decision tools for improved soil, nutrient, and water management developed and disseminated.

TSBFI-Africa

Published Work

Laboratory validation of a resource quality-based conceptual framework for organic matter management

B. Vanlauwe, C Gachengo, K Shepherd, E Barrios, G Cadisch, CA Palm

Soil Science Society of America Journal, 2004, In Press

Organic resources (ORs) are essential inputs in tropical farming systems and their decomposition dynamics are related to their quality. A Decision Support System (DSS) for organic N management has been proposed earlier that subdivides ORs 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 ORs, mostly crop and tree residues, applied to a sandy loam soil. The ORs contained 1.4 to 53.2 g kg^{-1} N, 25 to 295 g kg^{-1} lignin, and 4 to 148 g kg^{-1} soluble polyphenols. In-vitro dry matter digestibility ranged from 70 to 820 g kg^{-1}. After 28 days, CO_2-C production varied between 199 and 905 mg CO_2-C kg^{-1} soil, and mineral N contents ranged from 5 to 109 mg N kg^{-1} soil. Based on N mineralization data, 3 classes of ORs were evident: class A with N release > 0, class B with N release ≈ 0, and class C with N release < 0 (N immobilization). Criteria to separate those classes were based on the OR N and polyphenol content and cut-off values between the classes agreed well with those proposed in the original DSS. For class A ORs, N mineralization was negatively related to their lignin/N ratio (except for *Gliricida* residues) and for class C ORs, N immobilization was positively related to their N content. Short-term mineralization data supported the existence of 3 classes of ORs instead of 4 originally proposed by the DSS. However, ORs also govern other functions, operating in the medium to long term, and for these functions, the original 4-class concept may be proven valid.

Decomposition and Mineralization Rates of Organic Residues Predicted Using Near Infrared Spectroscopy

Keith D Shepherd, Bernard Vanlauwe, Catherine N Gachengo, and Cheryl A Palm.

Plant and Soil, 2004, In Press

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 precision of near-infrared spectroscopy (NIR) for direct prediction of *in vitro* dry matter digestibility (IVDMD) and C and N mineralization rates for a diverse range of organic materials 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 reference methods. IVDMD and C and N mineralization rates were predicted more accurately from NIR than using 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 reference versus NIR predicted values were for IVDMD, 0.88; C mineralization, 0.82; and N mineralization, 0.87. Precision was higher with NIR than the original reference methods: on average NIR halved the measurement standard deviation. NIR should be used for routine prediction of decomposition and nutrient release characteristics of organic residues. Priority should be given to construction of spectral calibration libraries in centralized laboratory facilities using standardized methods for determining organic resource quality and decomposition dynamics.

On-going Work

Using community-based learning to promote farmer experimentation and innovation with ISFM options in western Kenya

J.J. Ramisch, M.T. Misiko, I. Ekise, J. Mukalama (TSBF-CIAT)

Since 2001, farmer research groups (FRG) in four sites of western Kenya (Emuhaya, Vihiga district; Matayos and Butula, Busia district; Chakol, Teso district) have been experimenting on an ever-increasing number of ISFM principles. The approach used, termed "strengthening Folk Ecology" relies on collective demonstration and experimentation activities testing key principles (soil nutrition, organic resource quality, effects of legume rotation) followed up by individual experimentation applying these principles within ISFM technologies adapted to local priorities and conditions. When the activities began in 2001-02, only five FRG were active in the process, and only one collective activity (a demonstration in Emuhaya) was proposed and completed. However, through the course of interactions between the FRG's and the stimulation of dialogue between FRG's and researchers, the activities have continued to grow substantially, including now 12 FRG, 8 active collective activities that include much more experimental learning than simple demonstration, and a wide range of over 100 individual experiments designed to test and adapt the ISFM technologies.

Highlights of the farmer-researcher interaction process include:

1. Using "simpler" topics as entry points permits long-run empowerment and co-learning. The original experiments in all sites explored local and scientific understanding of soil nutrition. The demonstration plots tested the effectiveness of organic resources of differing qualities (guided by the Organic Resource Database criteria of nitrogen content, lignin, and polyphenol contents) on improving crop yields. At the same time, organic resources were combined with different treatments of inorganic N and P to allow the interactions of organic and inorganic inputs to be contrasted with those inputs used on their own. Farmers agreed that this design could be understood as a relatively simple experiment, whose findings could be readily explained to other group members and then later to visitors, such as other farmer groups or outsiders. The confidence instilled by this first step fed directly into new sets of questions and research objectives for the farmer groups in subsequent seasons.

2. Similar "lessons" have inspired very different follow-up activities in the different sites. It was expected that local concerns and priorities would lead the different FRG to eventually conduct different follow-up activities, however divergent interests became apparent immediately after the conclusion of the first experiments on crop nutrition and resource quality. Coordinating research efforts, so that different sites could learn from each others' experiences has become quite a challenge, walking a fine balance between supporting FRG to test the same concepts independently in different sites and facilitating innovation in unique directions. At the close of 2004, FRG experiments now include: the use of dual-purpose or high biomass grain legumes in rotation with the standard maize-bean intercrop, identifying and applying new high quality materials from local vegetation that would perform "like tithonia", improving the quality of farmyard manure and compost through selective management of inputs and control of aeration, and applying organic resource quality concepts and inorganic fertilizers to non-cereal crops, such as market vegetables (sukuma wiki) or to home garden crops (see discussions below).

3. Experimentation and learning on ISFM topics stimulated group empowerment for other topics. Without explicitly planning the research as "action" research, virtually all of the FRG have gained substantial confidence and skill from their ISFM activities. The social capital that has formed through the course of several years of collective and individual ISFM experimentation has been applied in several ways. First, as the numbers of interested farmers grew, and as tensions over research priorities increased, several of the FRG have split off from original members to pursue their own activities. Thus the numbers of participating farmers has increased through a fissioning of the original FRG, a scaling out process that has relied on founder members looking for and recruiting new members to join them in mutually interesting activities. Second, as part of this fissioning, group activities have broadened considerably beyond ISFM to now include topics as diverse as raising poultry or rabbits for market, running "merrygo-round" investment services for members (part of Kenya's "table banking" movement), and addressing health and nutrition, including the palliative care of people living with HIV or AIDS.

Farmer evaluation of soybean processing options

J.J. Ramisch, M.T. Misiko, I. Ekise, J. Mukalama, V. Munkangwe

Farmer research groups in Western Kenya are increasingly seeing good potential for the growing, consumption, and marketing of grain legumes, particularly high-biomass soybeans, in rotation with their current maize-bean intercrop. To promote wider use and appreciation of soybean, the Emanyonyi farmer group (Emuhaya division, Vihiga district) invited TSBF-CIAT and the local Ministry of Agriculture to a cooking and nutrition demonstration held at their farmer field school site on 5 October, 2004. This event was used to demonstrate the use of soybeans in preparing typical foods of Kenya (chapatti, mandazi, tea, infant formula, fried soya nuts) as well as novel products (cakes, "milk", livestock feed mix). Farmers were interested to see so many uses for the crop, but researchers also wanted to evaluate to what extent these new foods would be acceptable or could integrate into local diets. A participatory evaluation activity after the cooking event helped to score the various products as follows:

Table 34. Participatory evaluation of soybean products, Emanyonyi FFS (26 women, 12 men).

Product	**Taste (Sweet-ness)**	**Mouth-feel (Softness)**	**Work**	**Cost**	**Satisfaction**	**Able to stay fresh**	**Smell**	**Nutritive value**	**AVERAGE**
Chapati	3	3	2	1	3	2	2+	3	**2.37**
Milk	2	-	1	3	3	2	3	1	**2.14**
Mandazi	3	2	1	1	3	2	2	3	**2.12**
Chai	2	-	1	3	2	-	1	3	**2.00**
Livestock feed	3	-	2	3	1	1	1	3	**2.00**
Cake	1	2	2	2	2	2	2	3	**2.00**
Karanga (fried)	3	3	1	1	1	2	1+	2	**1.75**
Infant porridge	1	-	1	1	3	2	1	3	**1.71**

Items were scored versus the "standard" non-soya product, 1=inferior, 2=just the same, 3=superior

Three of the products were considered superior to the "standard" non-soybean product, namely chapatti (a flat bread that accompanies meals), mandazi (a deep fried bread eaten as a snack or breakfast), and the soy "milk" (Table 34) Tea and livestock feed made using soya were considered no better or worse than the non-soya versions – the soybean cake was also considered comparable with the "normal" cake but only a handful of the participants felt able to judge this particular item since cakes are not a common food item. The fried soybean was considered an inferior alternative to fried groundnuts, popular in the area, because they required a great deal of oil. The infant porridge was felt to have too strong a taste in the version proposed – participants suggested several ways to use soybean in a porridge that would not be refused by children.

This activity showed that adoption and wider use of dual purpose soybean varieties will rest not just on their soil fertility improving properties but also on the usefulness of the grain produced. Ready markets do exist for soybean in western Kenya, but a strong domestic demand will help drive adoption. Activities like this one, initiated by the farmers themselves, are a promising sign that awareness and adaptation of the crop can be promoted with minimal investment by research bodies.

ISFM options developed and tested to specifically benefit resources controlled and managed by women (e.g. Home gardens)

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A year-long study was conducted in three sites of western Kenya to evaluate the extent to which women are actively managing the soil fertility of home gardens (typically located on the patches of land that farmers identify as the "richest" site on the farm) and whether ISFM interventions would be able to contribute meaningfully to the yields of garden vegetables. Farmers used collectively managed plots to test inputs on local varieties of leafy green vegetables and also to screen new (disease or drought-resistant) varieties of familiar vegetables. The collective experimentation process was accompanied by detailed participant observation of key informants and their management of gardens. In general, participants in all three sites found the experimentation with vegetables to be extremely rewarding, especially since this was the first time that ISFM was being explicitly demonstrated on vegetable crops. Many felt that it was more worthwhile than the "traditional" experiments that had been conducted on maize, since garden crops are more likely to be grown on small plots such as those used in experimental designs, and for many this was also the first time that they were actively managing the agronomy of vegetables (local practice is to let vegetable crops grow "wild", without weeding, thinning, or attention to crop nutrition). The wealth of data collected from this study is being analysed as part of an honours thesis at the University of Toronto.

Cultivating complexity: Local soil ecological knowledge and the management of home gardens in Western Kenya

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Poster presented at World Agroforestry Congress, Orlando, Florida, 29 June, 2004

The value of "local agro-ecological knowledge" is increasingly promoted by both international and national scientific "professionals" as a major contributor to natural resource management in East Africa. This increasing interest can be attributed to several factors, including the failure of technicist interventions to stimulate agricultural productivity, to reverse or even halt apparent continent-wide problems of soil fertility decline, and also the increasing use of multidisciplinary teams to address natural resource management.

This paper looks at how local soil fertility management practices in western Kenya are informed by knowledge that has been generated and refined experientially. Such knowledge is responsible for the creation and maintenance of various "hot spots" within any given farmscape, most notably the "home garden" for vegetables, medicinal plants, and other valued species. Specific examples will show how the management of these niches reflects dynamics of power and decision-making within the household, and also the broader framework of gender relations and communities' access to information and markets.

The role of local soil ecological knowledge in managing home gardens serves as a useful entry point for examining the more general question of how households allocate capital (financial, human, and natural) to the maintenance of soil fertility on small-holder farms in Western Kenya. It is important to recognise that soil fertility managers and researchers alike must understand the strengths and limits of local knowledge before they can develop a "shared" knowledge base for soil fertility management concepts.

Whose land degradation counts? Understanding soil fertility management in Western Kenya
(Paper presented at the African Studies Association, New Orleans, 10-15 November, 2004)

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Continental-level analyses of African land degradation are overwhelmingly negative and contrast markedly with much more ambiguous local-level analyses. Solutions to land degradation proposed at the macro-level are likewise dramatic and drastic, including replenishing soil nutrient capital or replacing existing farming systems with new varieties and new inputs. While micro-level studies do not suggest that all is rosy, it is clear that land degradation is embedded within wider concerns about livelihood viability. Local studies also reveal potential if not already viable production systems that can confront land degradation, but that taking these solutions to higher scales requires deeper understanding of the local agro-ecological knowledge (LAK) base.

The soil fertility management practices in western Kenya are informed by LAK that has been shaped by repeated social interactions between farmers themselves and between farmers, agricultural "technicians", and other outside "experts". There is thus no single, coherent "body" (or "system") of knowledge about soil, soil processes, or land degradation within any of the four communities studied, nor do practitioners view soil knowledge as distinct from other aspects of rural livelihood. Technically defined "land degradation" emphasises nutrient depletion and soil erosion, while LAK treats system decline more holistically, including attention to non-agricultural livelihood concerns. Scientific efforts to "validate" soil LAK in technical terms therefore can often backfire by trivialising it. Even well intentioned, "participatory" methods used to identify and evaluate LAK with a view towards integrating it with outsiders' scientific knowledge risk marginalising these local knowledges merely as "starting points".

TSBFI-Latin America

Completed Work

Testing Diagnosis of the NuMaSS expert system for N and P applications in corn-based systems

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Corn yield response to N, P and K fertilization in 31 site-years of on-farm replicated field trials was evaluated for watersheds in Tascalapa, Honduras and Calico, Nicaragua in 2003. Each trial consisted of 5 treatments: 1) control without fertilization, 2) 100 kg N ha^{-1} as urea, 3) 100 kg P ha^{-1} as triple superphosphate, 4) 100 kg ha^{-1} each of N and P, and 5) 100 kg ha^{-1} each of N, P and K (as KCl). Analysis of composite soil samples collected from each field replicate, prior to the establishment of fertilizer treatments showed that soils in the Tascalapa watershed had pH values ranging from 5.3 to 7.0, N (KCl) from 1303 to 4592 ppm, P (Olsen) from 3.1 to 13.4 ppm and a clay content 35%. Samples from sites in Nicaragua showed pH values between 5.9 to 6.2; $NH4^{+}$ between 1.37 to 2.37 ppm, $NO3^{-}$ between 0.99-9.35 ppm and a mean clay content of 43%. Yield and soil data were combined to evaluate how well NuMaSS predictions in Diagnosis module of the NuMaSS expert systems matched the field-observed yield responses with corn to N and P fertilization.

NuMaSS Diagnosis of N and P constraints for each site are compared with field-observed corn yields responses to N and P in table 35. Results for trials in the Honduras watershed showed that predictions by NuMaSS Diagnosis of the presence or absence of a N deficiency matched the field data on 7 of 8 farm sites. Predictions by NuMaSS Diagnosis of the presence or absence of a P deficiency, based on estimated Bray 1 P levels, matched the field data on 5 of 8 farm sites. Predictions by NuMaSS Diagnosis with the actual Olsen-extractable P data using a fixed critical value of 15 mg kg^{-1} P, matched field-observed yield responses in 7 of 8 farm sites.

NuMaSS Diagnosis of soil N in experiments from Nicaragua matched corn yield-based results on 22 of 23 farm sites. Diagnosis of the presence or absence of a P deficiency, based on estimated Bray 1 P levels, matched the field data on 16 of 23 farm sites. Phosphorus Diagnosis based on a fixed critical value of 15 mg kg^{-1} P, matched field-observed yield responses in 12 of 23 farm sites.

The number of "mis-matches" in the Nicaragua watershed between NuMaSS Diagnosis of a P constraint and field-observed corn yield responses to fertilizer P, raise questions about the software's estimates of critical soil P levels in these soils. Soils at most of these sites are believed to be Inceptisols with 2.1-dominated clay mineralogy, whereas most of the existing data and algorithms for estimating soil critical P values in NuMaSS comes from soils with clay mineralogy dominated by kaolinite and oxides.

Since very little field data on soil critical P levels was found in the existing literature for the region, new P fertilization trials were designed and are being installed during the current year.

Table 35. Comparisons of NuMaSS Diagnosis of soil N and P constraints with corn yield-based responses to N and P fertilizers in farm trials for the watershed in Tascalapa, Honduras and trials for the watershed in Calico, Nicaragua (2001 y 2001).

Farms	**N**		**P**		**Pred. Bray 1 P**[†]	**Pred. Bray 1 Crit. Level**[†]
	Predicted[§]	**Observed**[¶]	**Predicted**[†]	**Observed**		
Watershed in Tascalapa, Honduras (2001):						
Sol	Yes	Yes*	No	Yes*	24.9	8.1
Peña	Yes	Yes*	Yes	Yes*	7.4	12.6
Bonilla	Yes	No	No	No	9.8	8.1
R.Corea	Yes	Yes*	Yes	Yes*	8.4	10
J.Corea	Yes	Yes*	Yes	Yes*	5.8	8.1
Jes. Corea	Yes	Yes*	Yes	Yes*	7.7	8.1
D. Romero	Yes	Yes*	No	Yes*	23.4	11.3
P.Pérez	Yes	Yes*	No	Yes*	25.3	8.1
Watersehd in Calico, Nicaragua (2001):						
Torres	Yes	Yes	No	No	9.1	8.1
Castro	Yes	Yes	No	No	13	8.1
Arauz	Yes	Yes	No	No	24.5	8.1
Blandon	Yes	Yes	No	No	99	8.1
Diaz	Yes	Yes*	No	Yes*	10.9	9.4
Soza	Yes	Yes	No	No	11.1	10
Rojas	Yes	Yes	No	No	16	8.1
SOL	Yes	Yes*	No	Yes*	81.7	8.1
Watersehd in Calico, Nicaragua (2002):						
1	Yes	Yes	Yes	No	9	15
2	Yes	Yes	No	No	47	11
3	Yes	No	No	No	40	16
4	Yes	Yes	Yes	No	10	20
5	Yes	Yes*	No	Yes*	58	13
6	Yes	Yes	No	No	69	12
7	Yes	Yes	No	No	18	11
8	Yes	Yes*	Yes	Yes*	11	15
9	Yes	Yes	No	No	79	10
10	Yes	Yes	No	No	36	11
11	Yes	Yes	No	No	30	13
12	Yes	No	No	No	22	11
13	Yes	Yes	No	Yes	16	8
14	Yes	Yes	No	No	18	9
15	Yes	Yes*	No	Yes*	13	8

¶ Nutrient deficiency based on obtaining a 1 t ha^{-1} yield increase between the control and N alone or P alone treatments; in the case that such a yield response is only obtained between the control and the N+P treatments, both N and P are considered deficient and are denoted with an *.

§ NuMaSS predictions based on Honduras - humid tropical location, target yield = N+P treatment, grain/stover ratio = 0.75, previous land cultivation with unfertilized corn of unknown yield, Inceptisol and no data for soil organic matter.

† NuMaSS predictions based on clay content and Olsen P for each site. Since NuMaSS predictions with Olsen P do not adjust the critical P level for soil clay content (a fixed value 15 mg kg^{-1} regardless of the soil clay content), soil P values were converted to Bray 1 P (which does adjust critical P level with soil clay content) using the function *Bray 1 P = (Olsen P)/0.53*. This function was derived from a literature review and is similar to the conversion function of *Bray 1 P = -6.0 +1.8(Olsen P)* found for a clayey Oxisol in the Amazon of Brazil.

Evaluation of the CERES-Maize growth simulation model applied to the maize in Oxisols of the Eastern Plains of Colombia

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Tropical Soil Biology and Fertility (TSBF) Institute of CIAT

Acta Agronómica 52: 39-44 (2004)

Intensification of agricultural production on the acid-soil savannas of South America (mainly Oxisols) is constrained by the lack of diversity in acid (aluminum) tolerant crop germplasm, poor soil fertility and high vulnerability to soil physical, chemical and biological degradation. In 1993, a long-term field experiment (CULTICORE) was established in Carimagua, Colombia. The average annual rainfall and temperature are 2200 mm and 26°C, respectively, with a dry season from December to March. Soils are well drained and are defined as fine, kaolinitic, Isohyperthermic Haplustox (clay loam soil). The main objective of the field experiment was to determine the influence of various systems on soil quality and system productivity. As part of this work, the simulation model of CERES-Maize (DSSAT v3.5) was evaluated for its suitability to the tropical conditions. Initially we focused on six genetic coefficients of the maize variety (Sikuani V110), which were calibrated based on field experiments conducted at 3 locations, Carimagua, Palmira and Santander de Quilichao. The evaluation of the model presented close relation between the observed and the simulated data for the principal variables of response including grain yield, biomass and phonological characteristics. The validation of the model using data from CULTICORE resulted in a close relation (r^2=0.95) between the observed and the simulated data. Results indicated that the model could simulate very well the performance of maize variety in terms of production of grain and total biomass as well as other parameters such as days to flowering and days to harvest.

Land use planning in the Llanos of Colombia at landscape units: The case of Puerto López

L. Santana[1], N. Beaulieu[1] and Y. Rubiano[2]

[1]*Rural Innovation Institute(RII) of CIAT*

[1,2]*Tropical Soil Biology and Fertility (TSBF) Institute of CIAT*

GeoTrópico, volumen 2 (1), online: http://www.geotropico.org/2_1_Santana

In this article criteria and recommendations are advanced in support of the process of land use planning in the savanna land-ecosystem. The municipality of Puerto Lopez, Colombia is used as a case study to illustrate the problem. An analysis of landscape and soil characteristics was conducted, taking into consideration biophysical and management aspects, in terms of limitations and potentialities for crop and agroforestry production, and in terms of conservation of different geomorphic settings. The methodology included the overview and conceptual discussion of terms related to land use planning. Satellite LANDSAT TM and RADARSAT imagery was used to define landscape units. Soil data were used to characterize each landscape unit. Fieldwork allowed us to refine the study of soil and landscape relationships, by gathering georeferenced data of the terrain, current land use, and management. The most important findings were summarized in maps and tables.

On-going Work

Determination of the P buffer coefficients for the NuMaSS expert system

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[2] *Tropical Soil Biology and Fertility (TSBF) Institute of CIAT*
[3]*Comunities and Watersheds Project, CIAT*
[4]*ITC, Candelaria, Lempira, Honduras*

Sites were selected in Yorito and Candelaria, in Honduras to initiate long-term P and N fertilization trials during the current year. The experiments contain 5 rates (including a zero) of broadcast fertilizer P. These P treatments will be monitored for soil test P and enable the determination of the soils' P buffer coefficients for the NuMass expert system. Yield responses for several cropping seasons, probably of corn and common bean, will be related to soil test P values to estimate critical soil P values. A subset of 3 of these broadcast P treatments will be in factorial combination with 5 fertilizer N rates (0 - 240 kg N ha^{-1}). The intent of the NxP factorial is to further investigate potential interactions between these nutrients. In the NPK trials for the Tascalapa watershed in Honduras corn yield responses to either N or P only occurred when both nutrients were applied in combination. Contrastingly, yield response to N in 16 of the 21 sites at the Calico watershed in Nicaragua did not require a supplementary P application. A factorial combination of several N and P rates will allow further elucidation of this interaction between nutrients.

2.7 Identify socioeconomic and policy constraints to the adoption of ISFM options and test potential solutions
(see also 4.4 and 4.7)

TSBFI-Africa

Completed Work

Assessment of adoption potential of soil fertility improvement technologies in Chuka Division, Meru South, Kenya (M.Sc. defended)

Ruth Kangai Adiel[1]; D.M. Mugendi[1]; J.J. Ramisch[2]
[1]*Department of Environmental Resource Conservation, Kenyatta University;* [2]*TSBF-CIAT*

In experimental trials at Kirege primary school Chuka division, a number of soil fertility improvement technologies were demonstrated from which farmers were encouraged to voluntarily select and practice on their farms. This study evaluated the extent to which farmers adopted and adapted the demonstrated technologies and also identified the factors that influenced their adoption or non-adoption of these technologies. To do this a farmer follow-up study was carried out in Chuka division over a period of two cropping seasons. Data was collected using farm surveys, on-farm trials and visual records. The data was then subjected to logic regression and cost benefit analysis to determine important variables affecting adoption and the most profitable treatments of the new technology respectively.

Although inorganic fertilizers were considered farmers' most preferred option, the rates of use were low because of high local costs and restricted availability. Most farmers practiced soil fertility improvement technologies involving the use of cattle manure, which was readily available, although again in inadequate quantities to supply the required nutrients. Further, lack of access to credit and inadequate extension services were identified as some of the critical issues limiting effective adoption of soil fertility improvement technologies. Eighty (80) farmers adopted the soil fertility improvement technologies during the short rains season 2001. During the subsequent two seasons, 163 and 206 farmers representing an increase of 99% and 150% above the initial adopters started practicing the proposed soil fertility improvement technologies. Technologies involving the use of *Tithonia diversifolia* and

Calliandra calothrysus alone or in combination with inorganic fertilizer were readily adopted due to the high yields obtained. During the first season of farmer follow-up, tithonia + half rate of inorganic fertilizer gave the highest net benefit of Kshs. 50133 per hectare followed by the full rate inorganic fertilizer treatment with a net benefit of Kshs. 48568. Fertilizer treatment had the highest benefit cost ratio (BCR) of 7.5. Sole manure treatment recorded the lowest net benefit Kshs. 4601 and hence the lowest BCR of 0.9. However during the second season manure plus half-inorganic fertilizer recorded the highest net benefit of Kshs. 41567 with a BCR of 3.7. Farmer practice involving no input had the lowest BCR of 0.2 with a net benefit of Kshs. 9853.

Constraints to the adoption of the proposed soil fertility improvement strategies were identified as inadequate labour, poor yields observed from some of the technologies at the demonstration trial, inadequate organic and inorganic resources and laxity due to fear of failure. Logistic analyses of the factors affecting adoption of soil fertility improvement technologies identified gender, farmer's occupation, land size and land under food production as major factors significantly affecting adoption of soil fertility improvement technologies in Kirege location, Chuka division. In conclusion there is need for the researchers to put in mind the factors that might affect adoption of a technology in order to have high adoption rates in any given area.

4.3 OUTPUT 3. Partnerships developed and capacity enhanced for improving the health and fertility of soils of all stakeholders

Rationale

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

The challenge of building the social capital encompasses both the new and existing networks of scientists and other stakeholders (e.g.: AFNET, MIS, CSM-BGBD project). Within these networks, as within the individual project activities where TSBF-CIAT works in partnership with others (NARES, ARI's, NGO's), building social capital means ensuring that communication and co-learning support effective institutional collaboration and build confidence in the collaborative advantage afforded by partnerships. Networks run best with diligent coordination that responds to internal and external challenges. However, partnerships become truly empowering when stakeholders themselves recognize and exploit research and development opportunities. The activities prescribed here envisage tapping the potential of South-South collaboration and establishing strategic partnerships that can build learning strategies that to institutionalize ISFM approaches.

The second challenge, of building human capacity, is particularly acute in sub-Saharan Africa and Central America, where the lack of strong tertiary education systems and the chronic under-funding of NARES hamper the professional development of many of our partners. Since ISFM approaches are inherently holistic, effective training demands interdisciplinary cooperation to instill both a specialized knowledge and a competent understanding of the context(s) in which to apply it (the so-called "T-shaped" skill set). Again, working through new and existing networks and partnerships, TSBF-CIAT will continue to support training that offers cutting-edge bio-physical science, laboratory techniques, and also embraces holistic understanding of social, cultural, economic, and policy issues related to soil fertility management.

Building human capacity also applies to the relationship land users have with the products of research. At present, many ISFM technologies remain little used by farmers. This is commonly conceived of as a failure to disseminate the results of research, but can also be seen as indicating a fundamental failure of research to recognize, value, and address farmers' conditions and knowledge. Greater involvement of farmers in the technology design process (to adapt solutions to actual conditions) will not only generate more relevant and adoptable ISFM technologies but is also expected to facilitate the potential dissemination and up-scaling of these technologies through the better interaction and integration of indigenous and formal knowledge systems.

Finally, the lack of an enabling policy environment is made manifest by the often-contradictory policies relating to farm, village, or regional-level conditions. The poor functioning of local input and output markets distorts the incentives for resource conservation. Coherent policy options are needed to address the low added value of farmers' products, the general lack of marketing opportunities on the one hand, and the lack of appropriate infrastructure and mechanisms for input delivery on the other.

Milestones

- By 2005, AfNet, MIS, SARNET and BGBD Networks restructured and strengthened.

- Publications (i.e., journal papers, books, extension materials, policy briefs, etc.), workshops, documentaries, field days implemented by each project.
- By 2010, tools for dissemination of research knowledge developed by each project.
- By 2010, appropriate policies and innovative institutional mechanisms developed and promoted.

Highlights

TSBFI-Africa

- A successful 9th AfNet symposium on 'Improving Human Welfare and Environmental Conservation by Empowering Farmers to Combat Soil Fertility Degradation' was held in Yaounde, Cameroon, with 155 particpants attending.
- Two intensive trainings for AfNet scientists were conducted during the last quarter of 2003 and the last quarter of 2004, one on 'Participatory research and scaling up' and one on 'DSSAT Version 4: Assessing Crop Production, Nutrient Management, Climatic Risk and Environmental Sustainability with Simulation Models'.
- Currenlty, 9 special projects are providing resources for implementing AfNet trials and training activities across the whole continent.

TSBFI-Latin America

- Eight soil-plant-water laboratories from Guatemala, Honduras and Nicaragua made initial steps to develop a sub-network to foster quality control and information comparison /exchange on analytical procedures for nutrient management recommendations.
- Partners of the MIS consortium actively engaged in research and validation of the Quesungual agroforestry system.
- Tools, concepts and improved soil management technologies generated by the MIS consortium members under active process of dissemination.

3.1 Strengthen networking on ISFM methods

TSBFI-Africa

Published Work

The African Network for Soil Biology and Fertility (AfNet)

Bationo A., Kimetu J, Kihara J, Sanginga N.
Tropical Soil Biology and Fertility Institute of CIAT, P.O. Box 30677, Nairobi, Kenya

Soil fertility degradation has been described as the single most important biophysical constraint to food security in sub-Saharan Africa (SSA). Soil fertility decline is not just a problem of nutrient deficiency but also of 1) Inappropriate germplasm and cropping system design, 2) Interactions with pests and diseases, 3) The linkage between poverty and land degradation, 4) Often perverse national and global policies with respect to incentives, and 5) Institutional failures. Tackling soil fertility issues thus requires a long-term perspective and a holistic approach. The African Network for Soil Biology and Fertility (AfNet) of Tropical Soil Biology and Fertility institute of CIAT is devoted to overcoming this challenge. AfNet's ultimate goal is to strengthen and sustain stakeholder capacity to generate, share and apply soil fertility management knowledge and skills to contribute towards improved livelihoods of farming communities. This African-wide network has over 200 members from National Agricultural Research and Extension Services (NARES) and universities from various disciplines mainly soil science, social science and technology transfer. This paper highlights AfNet's main activities which include: Network field research activities, information and documentation, training and capacity building.

Research highlights on integrated soil fertility management in the Sahel

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Soil fertility is the most limiting factor for crop production in the Sahelian zone of West Africa. The region shelters the world's poorest people with the majority gaining their livelihood from subsistence agriculture. Per capita food production has declined significantly over the past three decades. Increasing population pressure has on the other hand decreased the availability of arable land and it is no longer feasible to use extended fallow periods to restore soil fertility. Therefore, there is urgent need to restore/ maintain soil fertility in order to increase agricultural production in this region and improve the farmers' livelihood. In the recent past, scientists have evaluated the potential of different technologies in addressing the soil fertility problem in the Sahel as approaches to increase food production. Research results have reported that yields can be increased three to five times with the improvement of soil fertility with organic and inorganic fertilizers. The combinations also improve an array of soil properties such as Organic carbon content, Cation Exchange Capacity (CEC) and pH. The main constraint to combining inorganic-organic is the high costs of inorganic fertilizers and the low availability of organic fertilizers at the farm level. Crop rotation and intercropping systems are especially important in yield improvement as compared to continuous practices. Rotation systems increase nitrogen derived from the soil and fertilizer use efficiency. Similarly, methods of application of organic and inorganic fertilizer sources enhance use efficiency. For example, hill placement of inorganic fertilizers and manure is superior to broadcasting. Another potential is use of locally available phosphate rock, which could be an alternative to use of high cost imported P fertilizers. Since P is the most limiting factor on most sahelian soils, its correction not only improve yields but also the efficiency of N and water use. A bottleneck to the use of these profitable soil fertility-enhancing technologies that have been researched is the low capacity of farmers to invest in these technologies. In order to have these technologies to reach millions of farmers, a new integrated soil fertility management (ISFM) paradigm has been adopted which integrates biological, physical, chemical, social, economic and political factors. Future research challenges include combining rainwater and nutrient management strategies to increase crop production and prevent land degradation, increasing the legume component for a better integration of crop-livestock production systems, exploiting the genetic variation for nutrient use efficiency and integration of socio-economic and policy research with the technical solutions. Another very important issue for research is how to increase crop biomass availability at farm level to alleviate the constraint of non-availability of organic amendments. Use of decision support systems, modeling, and GIS is important in order to extrapolate research findings to other areas in which the successful technologies can be expanded/ scaled out to reach several farmers.

This activity is through a continuing project that has developed and implemented a multi-institutional project in eastern Uganda – INSPIRE (Integrated Soil Productivity Initiative through Research and Education).

Dissemination and sharing of information on improved technologies: FFS field days, farmer exchange visits, feedback workshops, publications, radio programmes and training workshops for community development facilitators from government, NGOs and research originations, have enabled improved technologies to benefit more communities; sensitization of local leaders and policy makers; share project outputs among partners within the Consortium.

The linkage between the INSPIRE partners has enabled the Consortium to bring together researchers, extension workers, policy makers and farmers to conduct research for development. Through support from the Consortium, farmers are being linked to government development programmes such as NAADS and other source of agro-inputs, information and technical advice, such as, the NARO research centers and ARDCs. INSPIRE continues to bring other organizations on board to handle issues arising that concern land policy, marketing, gender and HIV/AIDS. For example, VEDCO and TASO.

TSBFI-Latin America

On-going Work

Existing diagnosis and recommendation criteria for MIS-member laboratories

A. Alvarado [1], J. Smyth [2] and M. Ayarza [3]
[1] *University of Costa Rica*
[2] *CRSP-USAID Consortium*
[3] *TSBF-CIAT*

The MIS consortium organized a 2-day workshop at Zamorano, Honduras in September 2003 with representatives from 8 soil-plant-water laboratories in Guatemala, Honduras and Nicaragua. Purpose of this workshop was to a) inventory lab procedures and services, and 2) explore development of a laboratory network for Central America.

All laboratories carry out soil analysis. Five of the them do also plant analyses, and 3 analyse fertilizers and lime materials. Six laboratories indicated having equipment for plant digestion and access to atomic absorption and spectrophotometers.

All laboratories determine exchangeable soil acidity with a 1 M KCl extract, but two of the labs extract exchangeable bases with an NH_4OAc solution adjusted to either pH 4.8 or 7.0. Among 5 labs reporting methods used for extracting soil P and micronutrients, one uses NH_4Oac. Six laboratories provided information on the criteria used for lime and fertilizer recommendations. Two of these labs recommend lime based on soil pH and the rest use a combination of exchangeable acidity and critical % Al saturation values. All labs base N recommendations on regional experience, but 4 labs make additional adjustments based on variables like soil organic matter, pH and/or textural analysis. Fertilizer P recommendations in 4 of the labs consider whether soil test P is low, medium or high; but none of the labs could provide prior field and laboratory calibration trials as a basis for their ranking of soil test P data.

Laboratory representatives were very interested in developing a sub-network to foster quality control and information comparison/exchange on analytical procedures and recommendations. The group prepared a 9-page draft of guidelines and procedures for a 'Regional Network of Soil-Plant-Water Analysis Laboratories in the Agricultural Sector', based on guidelines currently in use by a similar network within Costa Rica.

3.2. Develop strategic partnerships in capacity building to empower stakeholders

Detailed reporting of activities relating to the work of TSBF in linking to the projects of the Enabling Rural Innovation team in support of activities in management of natural resources, farmer experimentation etc are highlighted in the IPRA Annual Report.

3.3 Improve dissemination of knowledge on ISFM

TSBFI-Africa

On-going Work

Increase the visibility of knowledge-based and social solutions to soil fertility problems

J.J. Ramisch[1]; M.T. Misiko[2]; J. Mukalama[1]; I. Ekise[1]

[1]TSBF-CIAT; [2]Wageningen Agricultural University

One of the key demands of farmers involved in participatory research is that experimental results are never fed back to them, which makes sharing the findings of research (even if done hand-in-hand by researchers and farmers together) between farmers difficult. Many researchers have been strong on involving farmers in monitoring and evaluating the progress of jointly run experiments, using the Farmer Field School (FFS) methodology. However, once crops have been harvested many farmers feel that research "loses interest" and that activities where results are presented and discussed are still only "an after thought" or lead too immediately into planning for the next season without allowing farmers themselves to digest and interpret the findings on their own.

To help overcome these problems, TSBF-CIAT has been attempting to summarize and synthesize its research activities in western Kenya. This has taken a variety of forms, and is still being guided by feedback from farmers on which types of data and which manners of presentation are the most instructive and the most useful. Currently, the most popular format is printing the results of a given collective experiment on a single sheet of double-sided A4 paper, using colour photos of at least some of the group participants and presenting the yield data and some of the comments or observations made by the FRG and the research team in a variety of visual and numeric formats. These leaflets are inexpensive to produce and are easily printed locally if the need arises. Once the standard format was agreed to the greatest constraints are a) ensuring the information is properly presented in the most relevant local language (i.e. KiSwahili or KiTeso) and b) that appropriate photos demonstrating the key points are available using the local participants.

An alternative method now being employed for presenting information that has longer-term relevance than annual trial data was suggested by several of the FRG, namely the production of calendars. The idea is to use the calendar as a vehicle to feature information on the agronomic and ecological lessons gained from the group's experimentation (e.g. on managing home garden vegetables for food security). This information is presented in small sections arrayed around a prominent photo of the entire research group. Most households in the area keep calendars with attractive photos on display in their homes long after the passage of the end of the year, which ensures that the information that accompanies the groups' own photos will remain accessible much longer than a leaflet or brochure would ever be.

Assessing Approaches for Dissemination of Research-based Information to Farmers within their Livelihood Situations in Tororo District, Uganda.
Agwaru, G., Matsiko, F., Delve, R.J.
MSc thesis being finalized
Approaches to extension, like Conventional, and Training and Visit, that have been used in the past to disseminate information to the grass root farmers have often left out the farmers and at times treated them as objects of technology transfer. Recent approaches by NAADS and NGO's have emphasized participation of farmers in this process. This is intended to integrate indigenous knowledge with scientific knowledge that farmers obtain from a variety of sources, to enhance technology generation and dissemination. This study aims to assess the mechanisms used by NAADS, NGOs and research to reach different categories of farmers, what are the farmers' sources of information and what preferences do they have for the format and presentation of this information, and how the channels and formats used influence exchange of information. The livelihoods framework, which considers farmers' assets and environment, has been used to provide the basis for assessing the approaches through qualitative and quantitative methods. The research findings indicate that farmers are involved in multiple activities but lack important information, for example, on sources of improved seed, and post harvest-handling techniques. The use of indigenous knowledge has not fully solved most of these problems, whilst present extension approaches have not been able to target their efforts towards specific categories of farmers. The poor are left out because they lack the necessary assets; natural, social, financial, human and physical, needed to participate in these projects. Assessing technology demands and targeting information to different categories of farmers is critical if they are to be able to interpret and utilize this information.

Production of extension materials

Country	Topic
Western Kenya, Eastern Uganda, and Northern Tanzania	Integrated control of Striga, stemborers and declining soil fertility

Organisation of field days etc

Country	Topic
Central Kenya	Integrated Soil Fertility Management
Western Kenya, Eastern Uganda, and Northern Tanzania	Integrated control of Striga, stemborers and declining soil fertility

On-farm training of trainers, students

Date	Destination	Event or purpose
April 2004	Kenya	Training for PhD students working in Kenya on ureide technique for biological N fixation
August 2004	DR Congo	Training for trainers on improved soil fertility management practices

Training

Two intensive trainings for AfNet scientists were conducted during the last quarter of 2003 and the last quarter of 2004.
1) Participatory research and scaling up organized by AfNet in September 2003 at Arusha, Tanzania. This helped the scientists in better communication of research results with the end user (the farmer).
2) DSSAT Version 4: Assessing Crop Production, Nutrient Management, Climatic Risk and Environmental Sustainability with Simulation Models held in Arusha Tanzania, 23rd –28th August 2004. This training course was organized by the African Network for Soil Biology and Fertility (AfNet) of the Tropical Soil Biology and Fertility (TSBF) institute of CIAT and Project 5 of the Challenge Program on Water and Food- Volta Basin coordinated by ICRISAT and presented by the International Consortium for

Agricultural Systems Applications (ICASA), the training workshop introduced DSSAT v4 to 33 scientists, working in nine (9) different African countries. DSSAT is a comprehensive computer model for the simulation of crop growth and yield, soil and plant water, nutrient and carbon dynamics and their application to real world problems.
In the year 2003/ 2004, a total of 10 Msc and PhD students have been and are being trained within AfNet.

TSBFI-Latin America

Technical Bulletins

Two Bulletins published in Spanish are available for partners in the region and these were distributed at the Latin American Soils Congress held at Cartagena and Soil Quality Indicators workshop held at CIAT-Palmira.

a) Why and how to build-up an arable layer
b) A manual for the use of the minisimulator of rainfall.

A Colombian national workshop on soil quality indicators was held at CIAT-Palmira with the financial support of the Ministry of Agriculture and Rural Development of the Government of Colombia. This event was held from de 20 to 22 of October. The experiences gained at this event will be used to organize another workshop in Central America on soil quality indicators. Based on the outcomes of these two workshops, a position paper will be prepared with regional perspectives on soil quality and land degradation for the next International Soil Congress to be held in Philadelphia USA.

3.4 Strengthen linkage with regional organizations and advanced research organizations

TSBFI-Latin America

Completed Work

Combating land degradation and improving agricultural profitability in savannas and hillsides agroecosystems of Latin America
M. Ayarza, I.Rao, E. Barrios, E. Amezquita and M. Rondon.
Tropical Soil Biology and Fertility (TSBF) Institute of CIAT
In: A. Bationo, J. Kimetu and J. Kihara (eds). International Symposium of the African Network for Soil Biology and Fertility (AfNet) of TSBF Institute of CIAT. Improving Human Welfare and Enfironmental Conservation by Empowering Farmers to Combat Soil Fertility Degradation. Yaoundé, Cameroon, May 17-21, 2004.
Steep slope hillsides and acid-soil savannas are the dominant ecosystems of Tropical America. Hillsides cover about 96 million hectares in South and Central America and have important roles as reserves of biodiversity and source of water for downstream users. Agriculture in this region is often characterized by farming systems under which soils are degrading through nutrient depletion and erosion losses. It is estimated that 75% of agricultural land is under a process of degradation. Neotropical savannas occupy 243 million hectares in South America and are one of the most rapidly expanding agricultural frontiers in the world. Mono-cropping systems with high levels of inputs and excessive cultivation are accelerating the deterioration of soil physical properties as well as escalation of pest and disease problems. Governments and R & D agencies in the region are seeking for enduring solutions that revert poverty and land degradation problems in these regions. The maintenance of the natural resource base in the hillsides is vital to ensure livelihood of resource-poor farmers and to prevent their migration to urban centers where social problems are already endemic. The intensification of agricultural production in savannas requires acid soil (aluminium) tolerant crop/pasture germplasm, soil fertility improvement and

management of highly vulnerable physical properties. The group of TSBF-Latin America is developing concepts, management principles and tools that help individual producers and rural communities to improve their livelihoods by developing profitable, socially acceptable and resilient agricultural production systems based on Integrated Soil fertility Management. In this paper we summarize the main outputs of our research on: 1) nutrient cycling and soil-plant interactions; 2) integration of local and technical knowledge; 3) development of novel production systems; 4) strategies to replenish soil fertility and improve soil chemical, physical and biological properties and 5) carbon accumulation and gas fluxes in traditional and managed systems. Emphasis is given in the mechanisms developed to scale up/out knowledge and experiences amongst stakeholders in the region (producers, NARS and research institutions) and the possibility to foster South-South cooperation between Africa and Latin America.

The Georeferenced System on Soil Quality Indicators (GEOSOIL)

Y. Rubiano[1,2], E. Amézquita[2] and N. Beaulieu[1]
[1]*Rural Innovation Institute(RII) of CIAT*
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The Georeferenced System on Soil Quality Indicators (GEOSOIL) for the Colombian savannas was conceived as a tool of support to the decision-makers in land use planning. It allows to store, consult and process data soil and of his biophysics surroundings on different scales: plot, farm, community, municipality, department, region, and country. It operates from a relational database elaborated in ACCES 2000, composed by a series of structured tables with information at different hierarchic levels to allow the characterization of the properties of the soil. The morphologic and analytical elements of the soil are combined to conform indicators of quality by a qualification system that allows visualizing the degree and the number of limitations that could have a soil to be used in agriculture. The degrees of qualification, used are: (1) without limitation, (2) light limiting, (3) moderate limiting, (4) severe limiting and (5) very severe limiting. The quality of the soil is associated with the degree and number of limitations that diminish their productive capacity. In addition, GEOSOIL has modules in which the user can: (a) add or consult space characteristics and attributes of the soil; (b) visualize the interpretation of the quality indicators, grouped in limitation ranks; (c) determine the general aptitude of the soil for a specific culture by means of the comparison between supply (soil) versus demands (requirements of the crop); (d) calculate the fertilization rates (e) generate reports on the variability in depth of some characteristics, for one or more soil; (f) map the results by means of a link with the Geographical Information Systems, in the specific case for free software MapMaker or Spring (g) also it is possible to generate report to made geoestatistical to understand the spatial and temporal variability of the attributes that are being used as indicators..

On-going Work

Indicators of soil degradation and improvement: methodologies and approaches for their successful application to asses impact of land use at several scales in Hillside agroecosystem

M. Ayarza [1] and M. Somarriba [2]
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Land degradation is a major concern in the Central American region. Seventy percent of land is in process of degradation. The situation is worsened in hillside agro-ecosystems because of their inherent vulnerability and the high concentration of poor rural population in these areas. There is an increasing concern about this problem among farmers, local organizations, central government and policy makers. However, there is a lack of standardized field methodologies enabling stakeholder groups to assess the impact of interventions on soil fertility. The MIS consortium is organizing a regional workshop for Central America in order to share experiences in the use of tools and field methods to determine soil chemical, physical and biological degradation. The main objective is to identify simple, robust and reliable indicators to assess impact of a given land use on soil chemical, physical and biological conditions.

Best examples of indicators and methodologies will be presented within the Symposium of Land Degradation at the World Congress of Soil Science organized by the International Union of Soil Science to be held at Philadelphia in 2006.

Geosoil – a decision support system for land use planning

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GEOSOIL is a database tool that allows the storage of soil information from soil profiles and represented it in a soil map. For each new entry, it allows the user to enter the physical and chemical data that are available, without requesting the user to fill in all the fields. For soil characteristics that are not numerical, for example for texture or landforms, it allows the user to choose from a range of options, the choices he want. For a number of soil properties that can be used as indicators of soil quality, it produces a report of a diagnosis, using criteria established for the Colombian llanos. It allows the comparison of soil characteristics with the requirements for a given crop, and when the necessary chemical information is available, can produce a report of fertilization recommendations. The soil requirements can be imported from the CUFRUCOL database or be specified by the user. Allows the export of soil data and corresponding geographic coordinates to GIS programs for their mapping, or to geostatistical programs for a spatial analysis of variability and interpolation.

Validation of Geosoil in other Regions collaboration with CENIPALMA

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CENIPALMA the research institution for oil palm in Colombian, requested CIAT collaboration for the characterization of soils in the Central oil palm production area. The work involves the systematization of the information they have in 1:10.000 scale. GEOSOIL will be used to evaluate the soil distribution and its suitability for palm oil plantation. The soil parameters that define suitability will be included into the tool. Besides of that the tool will be improved to include socioeconomic aspects of oil production, farm sizes and tree distribution at different scales from farm to group or farms. The final objective is to define better soil management systems to increase productivity and sustainability trough the application of the concept of precision agriculture.

Improving Integrated Soil Fertility Management (ISFM) through South-South collaboration

M. Ayarza and A. Bationo

TSBF-CIAT

Soil fertility degradation continues to prove a substantially persistent problem both in Africa and Latin America despite proposals for a diversity of solutions and the investment of time and resources by a wide range of institutions. In recognition of this problem, the AFNET network of African soil scientists was formed within TSBF in 1998 while an inter-institutional consortium was formed in Central America in 1998 under the umbrella of the Soil Water and Nutrient Management (SWNM) Program. AfNet and MIS have accumulated enormous experience over the years on ISFM from a systems perspective, which increases the comprehensive fit between research and farmer's experience of land management. However, all this has been locked up with the specific regions in which each consortium has been in operation. Since each of these networks has a comparative advantage over the other, sharing experiences will be a great achievement. The network alliance will break the communication gap between the networks and the two continents. Each institution will bring the human resources, historical involvement with networks and partners, and an extensive range of research and development sites. A proposal is under development to improve capabilities of researchers, extension agents and farmers to use ISFM to combat land degradation through the South-South alliance between AFNET and MIS. The proposal includes the development of mechanisms to exchange knowledge, methods and tools across continents, the identification of common issues to develop joint proposals and, conduct network trials.

3.5 Promote awareness of ISFM issues with policy decision makers

3.6 Improve understanding of adoption and adaptation processes including identification of policy constraints and responses

TSBFI-Africa

Published work

Integrated soil fertility management: evidence on adoption and impact in African smallholder agriculture

F. Place[1], C.B. Barrett[2], H.A. Freeman[3], J.J. Ramisch[4] and B. Vanlauwe[4]

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Food Policy 28 (2003) 365–378

This paper reviews current organic nutrient management practices and their integration with mineral fertilizers in Sub-Saharan Africa with a view to understanding the potential impacts on a range of input markets. A number of different organic nutrient management practices have been found to be technically and financially beneficial, but they differ considerably as to their effectiveness and resource requirements. A review of African smallholder experiences with integrated soil fertility management practices finds growing use, both indigenously and through participation in agricultural projects. Patterns of use vary considerably across heterogeneous agro-ecological conditions, communities and households, but are stimulated by profitable commercially oriented agricultural opportunities. The potential for integrated soil fertility management to expand markets for organic inputs, labor, credit, and fertilizer is explored. We found that there are few direct analyses of these links and indirect evidence at this point in time is inconclusive.

On-going Work

Linking Farmers to Market: Challenges and Opportunities for Improving Rural Livelihoods in Communities affected by HIV/AIDS in Uganda.

A Ph.D. student has registered at BOKU, Vienna to conduct a study investigating the impact on HIV-AIDS on adoption of technologies and to see if increased income through niche markets is one option for increasing income to improve on food security, quality of the food eaten and access to medicines.Although organic agriculture (OA) is one of the fastest growing segments of the food sector world over, it needs to be noted that the transition to organic management and marketing systems is not only complex but constrained by a range of bio-physical, economic and social factors. While organic agriculture is meant to alleviate poverty, poverty remains one of the biggest barriers to organic agriculture. Many organic initiatives lack the capacity to focus on strengthening biological processes, building farmers capacity to learn, enabling rural innovations. Little or no research has ever addressed the changes in livelihood strategies and outcomes as a result of the introduction of agricultural innovations such as organic farming and their market opportunities. There is a dearth of empirical studies on the reciprocal effects of HIV/AIDS on organic agriculture, and the opportunities that organic agriculture and other innovations may offer to communities and households affected by HIV/AIDS in Uganda. Similarly, no study has addressed the challenges of increasing the market opportunities and linking farmers to markets in communities and households affected by HIV/AIDS. Whether organic agriculture, and its market opportunities are more suitable to PLWAs than other agricultural technologies. The study will combine participatory rural appraisal methods with conventional household sample survey questionnaires using stratified sampling protocols and desegregated by gender in the district of Kisoro and Hoima. The theoretical and analytical framework will be guided by HIV/AIDS livelihood framework as developed as suggested (Tumwine 2003), gender analysis in agriculture and natural resource framework, and participatory technology development and innovation theory. This proposed research will explore opportunities and challenges of linking farmers to markets, and developing market opportunities for organic agriculture compared to other agricultural innovations in the context of HIV/AIDS pandemic. It will further assist in to improve the understanding the reciprocal linkages between agricultural innovations such as organic agriculture, market opportunities, and health (HIV/AIDS and related illnesses). The results of the study will generate information, which can be used to improve capacity of farmers affected by HIV/AIDS on how they can operate efficiently by strengthening their marketing skills of organic farm products. The findings of this study will further feed into and strengthen existing information on developing appropriate marketing of organic farm products and organic farming practices to promote sustainable agriculture production; and the study findings will be shared with collaborating agencies and organizations involved (BOKU-CIAT) and other stakeholders involved in poverty reduction, national AIDS control and other public health organizations who are important stakeholders.

3.7 Initiate dialogue on issues touching on policies that enhance the attainment of sustainability of the TSBFI outputs

3.8 Develop and construct databases and information systems to be shared out among TSBF project partners

On-going Work

Communication and partnerships strengthened in the CSM-BGBD project through:

- 13 Internet based mailing lists.
- Web-based discussion forum.
- Members web-based database developed based on CIAT's Expertise.
- Project Website developed.
- Prototype Project Database software developed for data and information storage, access, query, sharing and analysis.
- Partnerships formed in the participating countries with farming communities and NGOs.
- Global training workshop on earthworms and ants is planned for December 2004.
- Mexico held seminar at the Benchmark site to create awareness and develop strategic partnerships with people working on the ground in July 2004.
- Kenya held a national workshop to sensitize government ministries, research institutions, farmers and national universities on the project.

- Three members of the Indonesian Team participated in a training course on ‘tools for rapid biodiversity assessment of soil invertebrates in the ASEAN region.
- Several MSc and PhD students are underway.
- India has pblished its book on BGBD review in India.
- Indonesia has published its book on BGBD review in Indonesia.
- Brazil has published its book on BGBD review in Brazil.
- Kenya has sent its BGBD review papers to be published in a special journal of Tropical Microbiology.

4.4 OUTPUT 4. Improved rural livelihoods through profitable, diverse and intensive agricultural production systems

Rationale

Intensification and diversification of smallholder agricultural production is needed to meet the food and income needs of the poor and cannot occur without investment in natural resource management, especially soil fertility. Investing in soil fertility management is necessary to help households mitigate many of the characteristics of poverty, for example, by improving the quantity and quality of food, increasing income, and resilience of soil productive capacity. Access to multiple stress-adapted and improved crop varieties and multi-purpose legume species, improved soil and water conservation practices and improved targeting to different categories of farmers, are a few examples of existing interventions.

Investment in improving soil fertility is not constrained by a lack of technical solutions *per se* but is more linked to lack of access to; information for improved decision making and analyzing trade-offs; inputs (e.g. fertilizers, credit and improved germplasm) and profitable markets.

Technical innovation to improve poor people's agricultural productivity can link the goals of improving small farm competitiveness, increasing assets, nutrition and income to the sustainable management of the natural resource base.

Milestones

- By 2006, cereal-legumes and livestock systems, with nutrient use efficiency as an entry point, tested and adapted to farmer circumstances.
- By 2006, Quesungual and other related agroforestry systems, with water conservation as entry point, including crop diversification strategies, tested and adapted to farmer circumstances.
- By 2006 increase farm income and production in at least 20 pilot sites in at least 6 countries.
- By 2007, banana and cassava based systems, with the relation between pest, diseases and ISFM as entry point, including novel cropping sequences, tested and adapted to farmer circumstances.
- By 2008 improved production systems have triple benefits of food security, income and environmental services.
- By 2008, farmers are testing and adapting improved production systems in at least 15 sites in 5 countries.
- By 2010, validated intensive and profitable systems are being demonstrated, promoted by partners and adopted by farmers in 10 countries.

Highlights

TSBFI-Africa

- Bananas in central Kenya and Uganda are a cash crop and most bunches are transported out of the region (mostly to Nairobi and Kampala respectively), with probable enhancements in soil nutrient depletion as bananas move away from a food security towards a cash crop.
- Dual purpose, promiscuous soybean varieties, produced in West Africa, retained these traits under Western Kenya conditions as shown by increases in nodulation, biomass production and grain yield but only after application of P fertilizer. Such varieties have great potential to enhance the soil fertility status when included in rotations as they contribute to an increase in net amount of N in the soil.
- The local demand for soybean in Uganda is estimated at about 100,000 MT most of this being consumed in the animal feed sector and oil extraction with little utilization in the food industry. The regional demand for soybean from Uganda is estimated at 150,000 MT annually most of which being

utilized in Kenya for animal feeds and oil extraction. Growth in demand of soybean is positively correlated to growth in consumption of livestock products such as meat, eggs and milk for which feeds are manufactured.

TSBFI-Latin America

- Fertilizer N equivalency of Cowpea, Mucuna and Vigna surface legume mulches was at least 67 kg N ha^{-1} in a maize-based experiment planted in San Dionisio, Nicaragua.
- Short-term tangible benefits, innovative technology, leadership and community participation are the most important drivers influencing in the development of Bright Spots of improved land and water management.

4.1 Evaluate system productivity using participatory approaches

TSBFI-Africa

Completed Work

Improving soil fertility through the use of organic and inorganic plant nutrient and crop rotation in Niger

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Niger is one of the poorest countries in the Sahelian zone of West Africa where soil fertility and rainfall are the most limiting factors for crop production. The majority of the people in this region depend on subsistence agriculture for their livelihood. The population pressure has decreased the availability of arable land and the use extended fallow periods to restore soil fertility is not possible. There is therefore a need to address these constraints through research on long-term soil fertility improvement to ameliorate the farmers' livelihood. Research results have shown that yields can be increased up to five times with the improvement of soil fertility using a combination of soil tillage, organic and inorganic fertilizers than under traditional practice. Crop yields have also been shown to increase substantially using rotation of cereals with legume or intercropping. Yields of pearl millet can be doubled following cowpea as compared to continuous pearl millet cultivation. These combinations can improve soil properties such as Organic carbon content, Cation Exchange Capacity (CEC) and pH. There is however a constraint to the applicability of combining inorganic and organic fertilizers due to the high costs of inorganic fertilizers and the low availability of organic fertilizers at the farm level. But this constraint can be addressed by incorporating grain legume production such as cowpea into the cropping system. The grain, which has high market value, can be sold for buying external inputs such as fertilizer and fodder used for animal feeding. The use of external inputs will result in an increasing biomass at farm level, which increases the crop residue for mulching to mitigate land degradation and increase productivity.

On-going Work

Evaluation of general characteristics of banana production systems in Kenya and Uganda through participatory rural appraisal

J Jefwa and B Vanlauwe
Banana production in Kenya and Uganda has not been matched by corresponding interventions in post harvest and marketing. To bridge the gap between production and markets, the capacity of farmers to access and produce bananas for specialty markets has to be improved. Major concerns in banana production systems are yield declines, reduced plantation life and shifts to annual crops, hence raising concerns in food security and sustainability in the region. Pests and diseases and soil fertility are cited as the main contributing factors in yield decline. Little progress has been made on Integrated Soil Fertility Management (ISFM), yet there is growing evidence that the extent of damage caused by pests and diseases is influenced by soil fertility.

The current project is implemented in the main banana growing region in Uganda in Mujwa and Mugwanjura cells (smallest administrative unit equivalent to sub-locations in Kenya) in Butare Parish, Ntungamo district. The two cells are major producers of cooking and desert bananas, main banana collecting centres to Kampala and Kabale, pests and disease constraints are prevalent, decline in production and has soil related problems such as soil runoff. The target site in Kenya is Maragua district, the leading banana producer in the central province. Both Desert and cooking bananas are grown with approximately 20% of bananas grown from tissue cultured materials. The study is being undertaken in four sub-locations (smallest administrative unit), Gakoigo, Ichagaki, Mbugwa and Kianjiru-ini.

A PRA survey was undertaken (i) to introduce the project to the target farming communities, (ii) to collect data and research information that is consistent with community needs and preferences as well as scientists, (iii) to gather information on farmer perception that will be used to increase understanding by following up with scientific analysis, and (iv) to collect data that will guide into the collection of baseline data, during a site characterization work, on the role, production level and constraints of banana within the farming systems that will finally be used in selecting representative farms for detailed monitoring.

The PRA data showed that banana was ranked as the most important food and also cash crop in Kenya (Table 36). Banana was sold for food (cooking and desert) and as beer. In Kenya, maize and bean farming was ranked first by all the community members because of its perceived importance as a staple food for the people of the area while banana farming was ranked second due to its significance in providing family income as well as meeting food needs of the community.

Table 36. Ranking of the most important food and cash crops.

	Kenya		**Uganda**	
	Food	Cash	Food	Cash
Bananas	4	2	1	2
Sweet potatoes	--	--	2	--
Beans	2	5	3	3
Finger millet	--	--	4	--
Maize	1	3	--	--
Tomatoes	3	4	--	--
Coffee	--	--	--	1
Tea	--	1	--	4

Framers mentioned road network, marketing, declines in yield which they attributed to pests and diseases and soil related problems (Table 37). In Kenya Lack of credit to purchase manure and fertilizer was a major constraint. Soil fertility and pest and diseases were also major constraints in Kenya.

Table 37. Production constraints of banana in Uganda and Kenya

Rank	**Uganda**	**Kenya**
1	Infrastructure	Lack of credit
2	Pests and diseases	Pest and diseases
3	Marketing	Soil fertility
4	Land availability	Water stress
5	Technical advice	Lack of planting materials
6	Human diseases	Lack of technical skills
7	Labour	Poor prices
8	Tools	Poor infrastructure
9	Seed (planting materials)	Exploitation by middlemen
10	Yield decline	Theft of bunches
11	Declining soil fertility	Difficult bolting

In Kenya, soil fertility (declining or poor) was consistently ranked as being among the top five constraints to banana production (Table 37). In most cases lack of capital or credit was ranked highest because farmers need money in order to eliminate production constraints with soil fertility being one of the most prominent along with lack of water, and diseases and pests. The farmers in Kenya had a very clear perception of the fertility problem as demonstrated by the indicators of declining soil fertility listed during the survey. The following were used as indicators of declining soil fertility (1) declining yields (2) change in soil color (3) breakdown of soil structure (4) shift in weed species composition (5) surfacing of banana corms on the soil surface and (6) other indicators being stunted growth, smaller bunches, yellowing of leaves and production of fewer suckers. In Uganda farmers were aware of soil related problems but could not directly link them with soil fertility. Although ranked last, it is evident from soil management measures such as application of manure and mulch and contour terracing that there are soil related constraints.

Strategies as adopted by farmers for the control of pests and diseases (Table 38) in Uganda are: (i) banana wilt disease attacks desert bananas and is controlled by uprooting and chopping the infected banana and replacing it with another cultivar, (ii) Kiriro attacks all cultivars and is controlled by uprooting and destroying the infected plant, (iii) banana weevils attacks plantains and is managed through de-trashing (60 cm radius from the base), chopping pseudostem, uprooting old corms and weeding, and (iv) the toppling disease attacks all bananas and is controlled by propping (bunch support) and application of manure. Strategies as adopted by farmers for the control of banana weevil and nematodes in Kenya: application of ash, trapping, rouging removal of infected plants, burning around the plant, application of detergents (omo), chemical (Furadan), application of green or animal manure, kerosene, change of cultivar, application of hot water, application of hot pepper and field sanitation.

Table 38. List of diseases named by farmers.

Kenya		**Uganda**	
Pests	Diseases	Pests	Diseases
Slugs	Panama	Weevils	Banana wilt
Banana weevils	Sigatoka	Nematodes	Kiriro
Banana beetle	Cigar-end rot		
Thrips			
Nematodes			
Birds			
Aphids			

In both countries, it was observed that the export of nutrients in banana parts from the farms was more intensive. Banana in central Kenya and Uganda is a cash crop and most bunches are transported out of the region (mostly to Nairobi and Kampala respectively). The pseudostems are also used as fodder mostly for zero-gazed cattle. Even though the resultant manure is predominantly used to fertilize bananas, a significant part of the nutrients ends up in milk and meat. This means that the region can benefit from a well designed fertilization regime based on scientific data, taking into consideration the loss of nutrients from the farm with each harvest. This observation will hopefully be addressed in the nutrient omission experiments.

The data from the PRA survey is being used to characterize farming systems and collect baseline data on the role, production levels and constraints of banana within the farming systems. The site characterization data will finally be used to select representative farms for detailed monitoring. There is still a gap on fertilizer application in banana production; hence a nutrient omission trial is being established to identify the nutrients limiting banana production, the nutrients required, the critical and optimum nutrient concentrations and the potential production and recovery rates of fertilizers. Arbuscular Mycorrhizal Fungi have potential to improve performance and control diseases and pests of tissue culture bananas in poor soils. A green house mycorrhizal dependency experiment is in progress to evaluate the response of different banana cultivars to different AMF isolates.

Evaluation of the most limiting nutrients for banana production in Kenya and Uganda

J Jefwa and B Vanlauwe

Although much soil fertility related studies in EA highland banana systems have been conducted, there is a lack of basic knowledge on how much nutrients the AAA-EA banana plant requires, what its potential production is under well fertilized conditions, what nutrients are limiting plant growth in different areas, and what how much fertilizer needs to be applied to achieve the economic optimum for a certain target yield (i.e. target yield will largely depend on pest and disease pressure) and market price. The objectives of the current work are (i) to identify what nutrients are limiting highland banana production on the trial sites, (ii) to determine what the nutrient requirements are of highland bananas, (iii) to identify/confirm what the critical and optimal nutrient concentrations are in different plant parts of highland bananas, (iv) to estimate potential production of highland cooking banana, and (v) to determine recovery rates of fertilizers in highland cooking bananas, in order to allow the calculation of cost-benefits of different fertilizer recommendations.

The trials will be implemented in two sites in Uganda (Ntungamo and Kawanda) and one site in Kenya (Maragua). The treatment structure of the trial is presented in Table 39. While most of the treatments aim at determining the most limiting nutrients and responses to applied nutrients, 2 treatments (9 and 10) are investigating in a preliminary way how pest status affects nutrient uptake.

Table 39. Treatment structure of the on-station limiting nutrient trials for bananas.

Treatment:	1	2	3	4	5	6	7	8	9	10
N	X	-	-	½	X	X	X	X	-	X
P	X	-	X	X	-	X	X	X	-	X
K	X	-	X	X	X	-	½	X	-	X
Micronutrients	X	-	X	X	X	X	X	-	-	X
Pesticide	X	X	X	X	X	X	X	X	-	-

The objectives of T1-T8 are (i) to determine soil nutrient supply, (ii) to determine limiting nutrients, and (iii) to determine slope of the steep part of the response curve for N and K. The objective of T9-T10 is 9i0 to determine how nutrient uptake/recovery is affected by pests and (ii) to see how fertilizers affect plant pest status. The trials have been established during the short rainy season of 2004 and are expected to run for at least 3 ratoon crops.

TSBFI-Latin America

Completed Work

Yield response to fertilizer N and legume cover crops

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During the short rainy season of 2003/2004 an N fertilization and cover crop experiment was conducted at the Calico watershed in Nicaragua. The experiment contained 10 treatments with 3 replications: 6 rates of urea-N (0 - 200 kg ha^{-1}), split-applied in two equal applications at 25 and 55 days after planting, and 4 legume cover crops (cowpea, mucuna (*Mucuna pruriens*), rice bean (*Vigna umbellata*) and common bean), grown for 75 days and cut for surface mulch before planting corn. A uniform rate of fertilizer P was applied at planting of legumes and all fertilizer N plots.

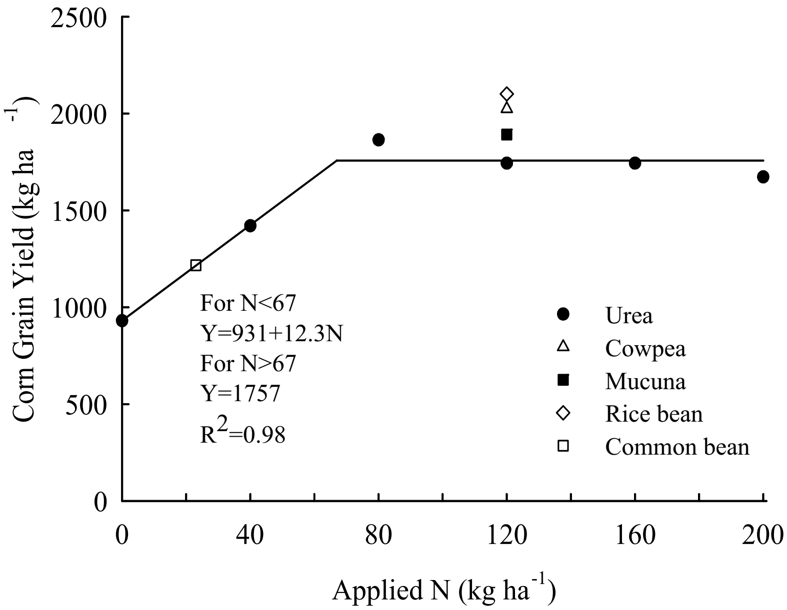

Figure 32. Yield response of corn to nitrogen applied as urea or through plant residues of five legume cover crops in an Inceptisol of San Dionisio, Nicaragua.

Corn grain yield increased with fertilizer N up to 67 kg ha^{-1} (Figure 32). The low yield plateau of 1.8 t ha^{-1} is attributed to limited rainfall during the September-January secondary growing season. Corn yields with 3 of the legumes (cowpea, mucuna and rice bean) exceeded the yield plateau by 0.1to 0.3 t ha^{-1}. Thus fertilizer N equivalency of these surface legume mulches is at least 67 kg N ha^{-1}. Corn yields with the surface mulch of post-harvest common bean residues was 1.2 t ha^{-1} and the urea-N equivalency was estimated as 23 kg ha^{-1}.

On-going Work

4.2 Develop profitable agro-enterprises linked to identified market opportunities (contribute production technologies/backstopping to agro-enterprise development within ERI project)

TSBFI-Africa

Detailed reporting of activities relating to the work of TSBFI in linking to the projects of the Enabling Rural Innovation team in support of activities in management of natural resources, farmer experimentation etc are highlighted in the IPRA Annual Report.

Published Work

Smallholder Farmers to Markets in East Africa: Empowering Mountain Communities to Identify Market Opportunities and Develop Rural Agroenterprises.
Sanginga, P.C., Best, R., Chitsike, C. Delve, R.J., Kaaria, S., and Kirkby, R. 2004.
Linking Mountain Research and Development 2004 24 (4) 288–291
The livelihoods of mountain farmers are often constrained by poor access to markets and limited entrepreneurial skills for adding value to produce. Research and development organizations have now recognized that improving market access and enhancing the ability of resource-poor mountain farmers to diversify their links with markets are among the most pressing challenges in mountain agriculture. What

is not so obvious is how to link small-scale farmers in marginal areas to growth markets, and how to develop methods and approaches that effectively integrate research, market access and development of community agroenterprise. The present article highlights the key steps and procedures in building capacity among farmers, farmers' groups, and communities, to identify and evaluate market opportunities, develop profitable agroenterprise, and intensify production, while sustaining the resources upon which livelihoods depend. This approach, known as Participatory Market Research (PMR) a component of the Enabling Rural Innovation (ERI) initiative is being implemented and further refined by the International Center for Tropical Agriculture (CIAT) in collaboration with research and development partners in Uganda, Malawi, and Tanzania.

Completed Work

Legume management: From process to market-led research
R. Delve.
A paper presented at the Rockefeller Soils Grantees Workshop 2004, Nairobi, Kenya
The paradigm of involving farmers in research is based on strong evidence that enhancing farmers technical skills and research capabilities, and involving them as decision-makers in the technology development process results in innovations that are more responsive to their priorities, needs and constraints. Linking process research and the technology development process to market opportunities has the potential to promote links between investment in natural resources, markets, and adoption of technologies. Market orientated agriculture for reducing poverty and environmental degradation needs to centre on three related paradigms; strengthening biological processes in agriculture (to optimize nutrient cycling, minimize external inputs and maximize the efficiency of their use); building farmer's capacities (to learn and innovate focused on improving livelihoods through market opportunity identification and the management of natural resources); and developing forward and backward linkages (between natural resources, production and markets). Examples of TSBFs and CIATs legume research in understanding processes, targeted germplasm development, adaptive testing of technologies and dissemination strategies will be used to show the evolution of legume research for ISFM and how increased market orientation can lead to increased adoption of improved technology options, investment in natural resource management strategies and provide valuable feedback for the research process.

Adding Value to Soil Fertility Research with Participatory Market Opportunities Identification: A Framework for Mainstreaming Market-led ISFM Research for Development
Sanginga, P.C., Kaaria, S., Muzira, R., Delve, R.J., Kankwatsa, P., Kaganzi, E., Sangole, N. and Pali, P.
Nutrient Cycling in Agroecosystems(in review)
The paper examines four hypotheses underlying market-led integrated soil fertility management (ISFM) research: (i) that linking smallholder farmers to profitable market opportunities will provide incentives for the adoption of ISFM technologies; and (ii) that the use of ISFM technologies will improve the competitiveness and profitability of agro-enterprises. Alternative hypotheses are that (iii) market orientation will lead to further depletion of soils; and that (iv) small-scale African farmers will not use mineral fertilizers. Results from case studies in Malawi, Uganda and Tanzania provide evidence that better market opportunities provide incentives to farmers to invest in replenishing soil fertility. But they need research and development to build their capacity to experiment and innovate to make agriculture more productive and competitive. The paper outlines a novel approach for demand-driven and market-led ISFM research. This approach termed the Resource-to-Consumption (R-to-C) offers a practical framework to link ISFM research to market opportunities identification in a way that empowers farmers to better manage their resources and offers them incentives to invest in soil fertility improvement. The R-to-C approach uses participatory processes to build the capacities of farmers, farmers' groups and communities to identify and evaluate market opportunities, develop profitable agroenterprises, intensify production through experimentation that create a demand for ISFM technologies. Mainstreaming market-

led ISFM requires significant changes in scientist's roles and approaches to research. These should include building and managing effective partnerships, linking technology development to market opportunities, stimulating farmers' experimentation, supporting efficient input markets, building capacity at different scales, and influencing policy change.

Soybean varieties, developed in West Africa, retain their promiscuity and dual-purpose nature under Western Kenyan conditions
B Vanlauwe, J Mukalama, R Abaidoo and N Sanginga
Entry points that give farmers immediate benefits are required to reverse the ever-declining soil fertility status of a substantial area in sub-Saharan Africa. In West Africa, dual purpose, promiscuous soybeans that produce a substantial amount of grains and leafy biomass and do not require inoculation with specific *Rhizobium* (rhizobia) strains were developed and have increased resilience of farming while providing income to farmers. These crops could be a potential entry point for soil fertility improvement in Western Kenya, provided they retain their promiscuity and dual-purpose character in this new environment. The major objective of this work was to quantify nodulation, biomass production and grain yield characteristics of a set of best-bet dual purpose varieties relative to a locally available variety at two sites (Vihiga and Siaya Districts) in Western Kenya. In presence of P, most promiscuous soybean varieties showed substantial improvements in nodulation (19 to 165 nodules per 0.5m of soybean) than the local variety (3 to 13 nodules per 0.5m of soybean). While grain yield was for all but one variety as good as the local control (845 kg ha^{-1}, on average), nearly half of the varieties produced significantly higher amounts of biomass at 50% podding than the local variety (865 kg ha^{-1} in Siaya and 1877 kg ha^{-1} in Vihiga). Increases in nodulation, biomass production and grain yield were mainly observed after application of P fertilizer; in absence of P almost none of the varieties performed better than the local control for any of the measured characteristics. To fully exploit the potential soil fertility improving characteristics of these varieties, it will be necessary to facilitate availability of P fertilizer and to foster demand at the farm, community, and national level.

On-going work

Enabling rural innovation in Africa: An approach for integrating farmer participatory research and market orientation for building the assets of rural poor
Sanginga, P.C., Best, R., Chitsike, C. Delve, R.J., Kaaria, S., and Kirkby, R.
To be submitted to Agricultural Systems
Agricultural research and development organizations are increasingly under pressure to shift from enhancing productivity of food crops to improving profitability and competitiveness of small-scale farming, and linking smallholder farmers to more profitable markets. What is not obvious however, is how to make small-scale farming more market orientated, and how to effectively integrate participatory research approaches to marketing and agroenterprise development. This paper outlines an integrated approach for demand-driven and market-orientated agricultural research and rural agro-enterprise development. This approach termed Enabling Rural Innovation (ERI) offers a practical framework to link farmer participatory research and market research in a way that empowers farmers to better manage their resources and offers them prospects of an upward spiral out of poverty. ERI uses participatory processes to build the capacities of farmers' groups and rural communities in marginal areas to identify and evaluate market opportunities, develop profitable agroenterprises, intensify production through experimentation, while sustaining the resources upon which their livelihoods depend. The approach emphasizes integrating scientific expertise with farmer knowledge, strengthening social organization and entrepreneurial organizations through effective partnership between research, development and rural communities. By strengthening human and social capital, ERI encompasses effective and proactive strategies for promoting gender and equity in the access to market opportunities and improved technologies, and in the distribution of benefits and additional incomes.. Results of action research applying the ERI approach in pilot sites in Malawi, Uganda and Tanzania show that small-scale farmers

are not always attracted by higher economic returns. Rather they use a range of economic and non-economic criteria for selecting their existing crops and livestock for new markets, as well as new crops for new markets. Evaluation of market opportunities stimulates farmers' experimentation to reduce risks, access new technologies, and improve the productivity and competitiveness of the selected enterprises. Lessons learned suggest that building and sustaining quality partnerships between research and development organizations, government, private agribusiness sector; and building necessary amount of human and social capital over a certain period of time are critical for achieving success in small- scale agroenterprise development. This however, requires that an explicit scaling up strategy be mapped out to link successful community processes to meso and macro level market institutions at the national and regional levels.

Evaluating the marketing opportunities for soybean and its products in Kenya, Uganda, and Tanzania

J Jagwe, B Vanlauwe

A regional soybean market study that includes Uganda, Tanzania, and Kenya has been implemented by Foodnet during June – September 2004. The purpose of the study is provide information that would benefit private sector stakeholders with the intention of investing in the soybean sub sector. To achieve this, the study reviews the various options for utilising soybean and the requirements for scaling up its production and utilisation in the target countries. The study also explores the market opportunities that can be seized by these countries in regards to its competitiveness in soybean production in the East African region.

The Ugandan study comes at a time when there is increasing quest for information by the private sector on soybean production, utilization and market opportunities and this has been very much championed by a group of stakeholders. These include researchers from NARO and Makerere university faculty of Agriculture, private sector partners from Mukwano Industries Ltd., which is very interested in oil seeds, animal feeds and nutritive foods, the vegetable oil development project and a private soybean farmer association known as the National Soybean Network based in eastern Uganda. The methodology employed by the study was based on a rapid assessment technique using primary and secondary data. Primary data has been obtained through interviews with producers, traders, retailers and exporters. Secondary data was acquired by literature review and the collection of available statistics. Fare scrutiny of secondary data sources ascertains the current level of soybean production in Uganda to be 187,000 MT having risen steadily from 101,000 MT in 1999. The yield has remained more or less constant ranging between 1.0 MT to 1.2 MT per Ha. The production methods remain crude characterised by poor seed, no use of fertiliser, no use of chemicals and poor crop husbandry practices.

Findings from this study reveal that most soybean production in Uganda occurs in the East and northern parts of the country and the cost of production estimates range between US$ 168 to US$ 184 per MT with current production methods. It is believed that with better crop husbandry practices and better utilisation of production inputs, the cost is likely to come down significantly. A comparison with United States soybean producer prices which range between US$ 160 and $ 180 per MT indicates that soybean production in Uganda is quite competitive. The local demand for soybean in Uganda is estimated at about 100,000 MT most of this being absorbed in the animal feed sector and oil extraction and little utilisation in the food industry. The regional demand for soybean from Uganda is estimated at 150,000 MT annually most of which being absorbed into Kenya for animal feeds and oil extraction. Growth in demand of soybean is positively correlated to growth in consumption of livestock products such as meat, eggs and milk for which feeds are manufactured. This growth is conservatively estimated at 5% annually depending on growing urbanisation and change in consumer habits. Oil extraction is a possible option for soybean utilisation but the method of extraction is vital given that soybean has an oil content of only 19%. Solvent extraction is the most recommended method yet it requires high capital investments that cannot be justified by small volumes processed. Findings from the study reveal that oil is currently being extracted using mills and presses and only 10% level can be achieved. Recommendations highlight the importance of bringing together stakeholder in soybean sector to explore opportunities of utilisation of soybean given the latest innovations that have resulted into the release of better varieties.

4.3 Evaluate system resilience of improved production systems (processes)
Work Completed

TSBFI-Africa

Published Work

Improving the productivity of sorghum and millet and farmers income using a strategic application of fertilizers in West Africa

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Poor soil fertility is the most limiting factor to cereal production in West Africa. The situation has worsened in recent years as increasing population pressure led to shortened fallow periods and expansion of agriculture onto marginal lands. As a consequence of this, crop productivity continues to decline. Although soil fertility enhancing technologies are available, they are not being adopted by farmers due to the high costs and unavailability of inputs, and the inappropriateness of the fertilizer recommendations. Recently, ICRISAT and its research and development partners have developed strategies to improve soil fertility on smallholder farms. This strategic application of fertilizers consists of applying small doses of fertilizer in the planting hills of millet and sorghum. The combination of the strategic point application of fertilizer with complementary institutional and market linkages , through an inventory credit system (also known as 'Warrantage') offers a good opportunity to improve crop productivity and farmers income. In the past two years, ICRISAT, in collaboration with other International Agricultural Reseacrh Centers, National Agricultural Research and Extension Systems and NGOs have been evaluating and promoting this point application of fertilizer along with the inventory credit system in three countries in West Africa, namely Burkina Faso, Mali and Niger. Results showed that, on average, in all the three countries grain yields of millet and sorghum were greater by 43 to 120 % when using the hill application of fertilizer than with earlier recommended and the farmers practice. Substantial net profits were obtained by farmers using the inventory credit system.

Long-term effects of crop rotations with groundnut and fallow on soil mineral N, nitrogen recovery, soil properties and crop yields in the Guinean zone of West Africa

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The effects of annual fallow and groundnut (*Arachis hypogea*) on soil N, N fertiliser recovery and subsequent sorghum (*Sorghum bicolour*) and cotton (*Gossypium sp*) yields were studied using a 10-year (1993-2003) old field. The experiment was carried out on the agronomic research station of Farakô-Ba (4° 20' West, 11° 6' North and 405 m altitude), located in the Guinean zone of Burkina Faso. A factorial 4x8 design in a split plot arrangement was used. Three sequences of rotation were used as first factor. Cotton-Groundnut-Sorghum and Fallow-Sorghum rotations were compared to mono cropping of sorghum. Each main plot was split into 8 sub plots and 8 fertilizer treatments (mineral NPK fertilizer, NPK+Crop

Residues, NPK+Dolomite, PK+Crop Residues, PK+Manure, PK+Compost, PK and Control) were applied as second factor. Crop yields were significantly affected by fertiliser and crop rotations but interaction was not observed between the two factors. Mean annual yields of succeeding sorghum increased from 547 kg ha^{-1} in continuous sorghum to 912 and 1021 kg ha^{-1} in Fallow-Sorghum and Cotton-Groundnut-Sorghum rotations respectively. Soils of Fallow-Sorghum and Cotton-Groundnut-Sorghum rotations released more mineral N at sowing and increased fertilizer N use efficiency from 13 and 32 units respectively compared to continuous sorghum. Soil organic carbon increased from 0.36% in continuous sorghum to 0.39 and 0.54% in Cotton-Groundnut-Sorghum and Fallow-Sorghum rotations respectively. Compared to original soil, continuous sorghum and Cotton-Groundnut-Sorghum rotations decreased soil organic carbon. Only Fallow-Sorghum rotation maintained soil organic carbon, exchange acidity and base saturation at same levels like those of original soil. Unlike organic C and total N, highest quantities of available P (P-Bray I) were observed in soils of mono cropping of sorghum and lowest quantities were observed in Fallow-Sorghum rotation. Manure applications increased soil organic carbon, total N and available P. Except for Fallow-Sorghum rotation, all rotations increased aluminium saturation and decreased soil pH compared to original soil. Manure or dolomite applications decreased exchange acidity and maintained soil pH and base saturation at same levels like those of original soil.

Millet yield and water use as affected by amendment type in a traditional land rehabilitation technique – zai

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Due to the increased population pressure and the limited availability of fertile land, farmers in the desert margins increasingly rely on marginal or even degraded land for agricultural production. The farmers rehabilitate these lands with different technologies for soils and water conservation. Among these is the zai, an indigenous technology for land rehabilitation, which combines water harvesting by means of small pits and hill-placed application of organic amendments. To study the resource use efficiency of this technique in the context of the Sahel of Niger, an experiment was conducted at two locations on degraded bare lands in a farmer field from 1999 to 2000. In these experiments, the effect of organic amendment type (millet straw and cattle manure, 3 t ha^{-1}) and water harvesting (with and without water harvesting pit) on millet grain yield, dry matter production and water use were compared. The results revealed that on soil with moderate native fertility, with non-amended zai holes, it was possible to produce 400 kg ha^{-1} of millet grain yield compared to the average yield of Niger of 300 kg grain ha^{-}1, whereas on highly degraded soils with low native fertility, only 20 kg ha^{-1} were produced. In consequence under such conditions, addition of good quality organic amendment is prerequisite for the success of the technology. Grain yield amounting to 900 - 1100 kg ha^{-1} were produced in zai amended with cattle manure compared to 450 to 700 kg ha^{-1} with traditional flat planting with the same amendment. High drainage occurred in the zai treated plots particularly when amended with crop residue. On cattle manure treated plots, the wetting front remained at shallow depth suggesting high water use probably resulting from higher evapotranspiration. Here plant available water was often exhausted throughout the cropping period particularly on plots without zai treatment. On average 1.6 kg grain was produced per unit rainfall in the zai compared to 1 kg for planting on flat. The extra yield is an indication of a better use of the limited rain available in the sahelian conditions.

Stochastic Dominance Analysis of Soil Fertility Restoration Options on Sandy Sahelian Soils in Southwest Niger

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Poor fertility of sandy Sahelian soils remains one of the major constraints to pearl millet (*Pennisetum glaucum* L.) production in West Africa. On-farm trials under farmers' management were conducted in two rainfall zones of Niger in 1996 and 1997 to evaluate the risk characteristics of 6 soil fertility restoration options. Stochastic dominance analysis was used to compare fertilizer treatments tested. Results show that farmers' traditional method (no fertilizer control), Tahoua phosphate rock (TPR) alone applied at 13 kg P ha-1 broadcast, and a combination of TPR broadcast at 13 kg P ha-1 and single super phosphate (SSP) hill placed at 4 kg P ha-1 had the most desirable risk characteristics and are acceptable to risk averse decision makers in both rainfall zones. At current input-output price ratio, most fertilizer-using farmers would choose the combination of TPR broadcast and SSP hill placed. If the availability of single super phosphate was limited, some farmers would use Tahoua phosphate rock alone. The demand for risk efficient alternatives could significantly increase if farmers could bear less than half the fertilizer costs at current output price.

4.4 Identify drivers of farmer innovation for adaptation and adoption of technologies

TSBFI-Africa
Published Work

The adoption potential of biomass transfer and improved fallow practices in eastern Uganda: Determining profitable and feasible options from a farmer perspective
Pali, P.N., Delve, R.J. and White, D.
NARO conference paper, published in Uganda Journal of Agriculture, In press
Many advocate for the use of organic and inorganic fertilizers to restore declining soil fertility. However, most farmers cannot afford to purchase inorganic fertilizers because they are beyond the budgets of most households. Limited access to both credit and markets prevent their use. Organic fertilizers are also a difficult option as small farm size and insufficient labor availability often hinder their production. To estimate the adoption potential of integrated fertilizer options by smallholder farmers, on-farm maize productivity trials were conducted with 10 farmers. The study contrasted twelve treatments of different levels of inorganic fertilizer with improved fallow (IF) species (*Mucuna pruriens* and *Canavalia ensiformis)* and the biomass transfer (BT) species (*Tithonia diversifolia).* Analysis identified optimal combinations of organic and inorganic soil improvement options at varied price levels of inputs and outputs to assess the sensitivity of outputs to price fluctuations. Profitability and associated required investments (capital, labor, and land) of the options within a farm context (labor and capital availability) were assessed using a linear programming model. Tororo district in eastern Uganda served as a case study where farms have on average 2 ha of land in 2 enterprise scenarios. All IF and BT treatments are profitable and were sensitive to labor and maize price fluctuations. The optimal treatment for the farmers scenario was found to be the farmer's practice for the Tithonia treatment and 1.8 t ha^{-1} of Tithonia on 1.9 ha of land, whilst for the proposed practice scenario, with all labor activities costed and a high value of maize used, the optimal mix was found to be the integrated use of Tithonia (0.9 tha^{-1}) and 30 kg inorganic nitrogen on 0.42 ha and N-P-K inorganic fertilizer on 0.495 ha of land. The optimal net benefit in each case could be US $780.1 and US $713.5 respectively. The result showed that a soil improvement practice could be incorporated into the farmer's field using the farmers' usual farming practice with a higher net benefit and if using the integrate approach, the land size should be reduced for economical reasons.

How can smallholder farmer-market linkages increase adoption of improved technology options and natural resource management strategies?
Robert J. Delve and Ralph L. Roothaert
NARO conference paper, published in Uganda Journal of Agriculture, In press
The paradigm of involving farmers in research is based on strong evidence that enhancing farmers technical skills and research capabilities, and involving them as decision-makers in the technology development

process results in innovations that are more responsive to their priorities, needs and constraints. Linking the technology development process to market opportunities has the potential to promote links between investment in natural resources, markets, and adoption of technologies. Market orientated agriculture for reducing poverty and environmental degradation needs to centre on three related paradigms; strengthening biological processes in agriculture (to optimize nutrient cycling, minimize external inputs and maximize the efficiency of their use); building farmer's capacities (to learn and innovate focused on improving livelihoods through market opportunity identification and the management of natural resources); and developing forward and backward linkages (between natural resources, production and markets). In a multi-stakeholder coalition, CIAT and its partners are working in Malawi, Mozambique, Tanzania and Uganda to explore and understand how market orientation leads to improved NRM at the farm level. This paper uses case studies from Uganda to highlight and discuss examples where identifying potential markets for existing and new products have led to increased investment in NRM.

TSBFI-Latin America

Completed work

Analysis of drivers associated with the development of Bright Spots: Are there key factors that contribute to the development of Bright spots and their sustainability?

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Final draft Report, Bright Spots Project-Comprehensive Assessment Program

Individuals and communities have developed ways of coping with and reversing natural resource degradation. There are numerous isolated examples around the globe of interventions that have been effective in reversing the continuous downward spiral of poverty and hopelessness wit positive impacts on land and water resources. These are often termed "Bright Spots" and can be defined as individuals, small communities and households that have adopted innovative practices and strategies to reverse degradation in a sustainable manner whilst maintaining or enhancing food security. In this study an assessment of the key drivers that influence the development o f Bright Spots was evaluated through a questionnaire survey of existing examples. Analysis of data indicates that depending on the form of Bright Spot development specific drivers were observed to have important role. In the case of community based projects (i. e., watersheds development projects) leadership, social capital and community participation were the three most important elements effecting the development of the Bright Spot whilst innovation ranked fourth. Contrasting to this, in the case of the 204 respondents that have implemented new improved methods of growing rice and wheat in south India and the Punjab, innovative technology, aspirations for change and short-term tangible benefits were the key elements associated with the development of the Bright spot.

Drivers effecting the development and sustainability of the Quesungual Slash and Mulch Agro forestry System (QSMAS) in hillsides of Honduras

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The Quesungual Slash and Mulch Agroforestry System (QSMAS) is a bright spot of improved land and water management for sub-humid hillside agroecosystems suffering severe seasonal drought periods. This system has contributed to improve livelihoods of more than 6,000 farmer households in the Lempira Department, Honduras. It is based in the management of dispersed native trees in cropping fields through periodic pruning. Competition is kept low while provision of plant residues for soil cover and nutrient cycling is maintained favorating soil moisture conservation and fertility maintenance. Annual crops and pastures are planted on no-burned fields with zero tillage/direct planting operations. This system enabled farmers to increase crop yields and reduce labor for weed control. Besides gains in crop improvement, the widespread adoption of the system is associated to an strong participation of the community in the development of the system and the implementation of local policies to avoid use of fire for agricultural purposes and incentives to promote overall welfare of the community. In this paper, we analyze the role of these factors behind the social acceptance of the system and make an attempt to derive lessons that could be considered for the extrapolation of the system to similar regions in Latin America and Africa.

Drivers affecting development and sustainability of no-till systems for smallholders at watershed level in Brazil

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The no-till system in Brazil can be considered as a bright spot of improved land and water management for tropical soils prone to soil and water losses under conventional land preparation methods. This system has contributed to enhancing the productivity and sustainability of annual cropping systems in both large and small farming units of the southern and cerrados regions of the Brazil. Smallholders adopting the system have benefited through reductions in labor and increased profits produced by the system. Widespread adoption of no-till in Brazil is associated to an strong participation of farmers in the development and implementation of the system and to policies and incentives to improve environmental land and water quality at the watershed level. The case study included in this paper ilustrates the positive linkages that were developed between farmers, local goverment and the private sector to improve public health, control soil erosion and reduce water pollution at the watershed level

4.5 Investigate alternate production options using trade-off and scenario analysis tools

TSBFI-Africa

Published Work

Pathways for fitting legumes into the farming systems of East African Highlands: A Dual approach

Tilahun Amede
Tropical Soils Biology and Fertility Institute of CIAT/ African Highlands Initiative

In: Waddington, S. 2003. Green legumes and Green manures for soil fertility in Southern Africa. Taking Stock of Progress. Proceedings of a Conference held 8-11 October, 2002. Leopard Rock, Vumba, Zimbabwe. Soil Fert Net and CIMMYT, Harare, Zimbabwe. 246pp.

Food legumes remained to be important components of various farming systems of Eastern Africa, while the attempt to integrate fodder legumes and legume cover crops (LCCs) became unsuccessful. Despite recognising their benefits as soil fertility restorers and high quality fodder, farmers remained reluctant to integrate legumes mainly due to community/farmer specific socio-economic determinants. This paper is written based on the experiences of the African Highlands Initiative that has striven to integrate legumes in Ethiopian Highlands, Areka, and also understand the processes of integration of legumes of different use through participatory research. Areka had an altitude of 1990 masl, and rainfall amount of 1300mm, which is characterised by mixed subsistent farming systems, poor access to resources, intensive cropping, land shortage and soil degradation. Participatory evaluation was conducted on the agronomic performance and adaptability of eight legumes for three consecutive years during the main and small growing seasons, accompanied by extensive data collection on socio-economic determinants. PR experiences showed that the selection criterion of farmers was far beyond biomass production. The major biophysical traits are performance of the species under that specific agroecology, which was characterised by yield, disease and pest resistance, effect on soil fertility and the succeeding crop and its compatibility into the existing cropping system. Specifically, farmers identified firm root system, early soil cover, biomass yield, decomposition rate, soil moisture conservation, drought resistance and feed value as important criteria. The total sum of farmers' biophysical criteria showed that Mucuna followed by Crotalaria could be the most fitting species, but farmers finally decided for Vetch, the low yielder, due to its fast growth and high feed value. Farmers' priority was livestock feed over soil fertility. The final decision of farmers for integrating a food legume into their temporal & spatial niches of the system is dictated by the food habit while for non-food legume it depended on land productivity, farm size, land ownership, access to market and need for livestock feed. The potential adopters of LCCs and forage legumes were less than 7%, while 91% of the farmers integrated the new cultivars of food legumes. Strategic combination of biophysical and socio-economic determinants in the form of decision guides was suggested to facilitate the integration of legumes to help farming communities, development agencies and researchers to easily identify potential adopters, learn about the criteria of choice and suggest an improved system management. Moreover, it may also help them to identify niches and/ or create niches, modify the existing systems and promote the technology for wider use.

Multiple models to enhance farmer innovation in sustainable nutrient management: AHIs' experience

Tilahun Amede

Tropical Soils Biology and Fertility Institute of CIAT/ African Highlands Initiative

In: German, L. and Stroud, A., 2004. Integrated Natural Resource Management in Practice: Enabling Communities to Improve Mountain Landscapes and Livelihoods. AHI Conference, 12-15 October, 2004. Nairobi, Kenya.

Continual food insecurity and deteriorating livelihoods of millions in East Africa is highly related to long standing decline in soil and human nutrient budget and poor distribution among system components and sub-units. Even with in the crop sector there are mixed enterprises variably attached to specific farm units, namely the house, homestead, mid field, outfield and pasture land and wood lots. Various participatory tools and models were used to increase nutrient enrichment, to minimize trade-offs in nutrient budget between various farm enterprises, to reduce mining of nutrients of specific farm units, to reduce excessive accumulation of nutrients of certain farm units at the expense of other farm units, and also optimize the nutrient budget of the people without mining the land based resources, which could be extrapolated to other communities and higher scales. Although a U-form relation between population pressure and nutrient management is needed to feed the ever growing population it became elusive to achieve it due to multiple causes. This paper will present potential tools and models to intensify the existing systems, namely:

1) DSS to identify spatial and temporal niches to increase organic biomass production of the system as increased use of chemical fertilizers may not compensate for the organic matter-related processes, particularly in the far out fields.
2) Designing strategies that could encourage farmer innovations to minimize nutrient mining of some farm units to enrich other enterprises
3) Fitting technologies with win-win benefits to attract collective interest of farming groups and communities to manage nutrients better
4) Models to design nutrient management in systems perspective with various scenarios considering socio-economic differences so as to minimize resource degradation while maximizing benefits that comes out of the system as food, feed and cash
5) Develop policy suggestion for system shift and nutrient input enrichment through bottom-up negotiations at individual farmer, community and district levels. Increasing awareness of the communities on nutrient cycles and disorders and its implication on human and system health.

Implementation of these innovations demanded a mix of technological & institutional interventions. The immediate impact will be improving the nutrient recycling of the system through manipulation of the existing household resources, which will have a considerable implication on soil and human health. Local institutions could be benefited by getting knowledge and methodology on how to quantify and optimize nutrient recycling of the current production systems to possibly minimize nutrient mining but reversing the current trends using the existing local resources. Strategies are suggested to enhance local innovation in improving sustainable nutrient recycling. This paper would present case studies where the above mentioned strategies have been tested in a participatory research frame work at plot, farm and higher levels in Ethiopia and Kenya.

Intensification Pathways from Farmer Strategies to Sustainable Rural Livelihoods: AHIs' Experience

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In: German, L. and Stroud, A., 2004. Integrated Natural Resource Management in Practice: Enabling Communities to Improve Mountain Landscapes and Livelihoods. AHI Conference, 12-15 October, 2004. Nairobi, Kenya.

Subsistence farmers in Eastern Africa face serious decline in soil productivity. They categorized themselves in relation to number & composition of animals, perennial crops, land productivity and size, health and social positions. General strategies towards sustainable livelihoods were to enable children to have thorough education, introduce family planning and improve agricultural productivity. The last had proven elusive, with few innovations being adopted despite various R&D attempts of governmental and non governmental institutions. AHI teams across the region tested various scenarios of participatory and integrative ways to enhance integration of technologies. Farmer research committees (FRC), planning with development agents and scientists, initially focused conservatively on crop varieties. Members now supply seed of selected varieties to others, while researchers learned their selection criteria. With growing confidence, farmers embarked on more complex issues. Multipurpose elephant grass on contours was enthusiastically taken up, followed by farmer experiments with herbaceous and agroforestry legumes. Farmers describe interacting effects: new fodder sources improved dairy production; maize stover is retained for soil fertility; mixing early- and late-maturing maize varieties opened a niche for a legume relay. Some farm-level constraints provoked border conflicts (e.g Construction of soil bunds), which demanded collective management and negotiation of waterways towards developing initial confidence to address higher community issues. The FRC's vision changed to self-reliance through enhanced local innovation, to placing technical demands on the public sector, and to assisting other communities. Lessons learned across AHI sites about systems intensification scenarios, FRCs and FFCs and the role of research are discussed.

On-going work

Use of a decision support tool (DST) for evaluation of trade-offs and scenario analysis, results of a collaboration between ILRI, ICRISAT, TSBF and national partners

This project used benchmark sites in Ethiopia, Tanzania and Zimbabwe to test and evaluate the DST and to conduct trade-off and scenario analysis.

Incorporating farmers perceptions, farmer production objectives and the farmers perceptions of risk and vulnerability into the modeling work was critical to enable the partners to refine their thinking and review the initial researcher based scenarios and develop farmer criteria based scenarios for crop-soil-livestock systems. Case study farmers were chosen to represent different farm types in each country, in terms of land size, wealth category, number of livestock, access to labor etc. Individual interviews were used to elicit information on seasonal calendars, labor allocation throughout the year, farm enterprises, production objectives and possible new enterprises. Also data on perceptions of risk and vulnerability and the trade-off between growing for food security and market orientation was investigated. Following these field trips, the data was input in to the DST and scenarios and trade-off analyses conducted. Return trips will be made to these same farmers to discuss the implication and projections of the DST results, to further refine the scenarios with farmers and re-run the DST though focus group and individual farmer discussions. The incorporation of farmers perceptions, farmer production objectives and perceptions of risk and were essential to generate relevant and realistic scenarios.

Areka, Ethiopia example

Tables 40-42 give an example of this process for a farmer in the highlands of Areka, Ethiopia. The initial situation of the land management of their farm is given in Table 40. In the present situation the farmer grows a mixture of crops and enterprises for food security and income generation and makes 2,381 Birr (approx. USD280).

Table 40. Existing land management for a medium wealth category farmer in Areka, Ethiopia.

Plot	Enterprise
Homestead	Enset, coffee, kale, sweet potato, maize
Mid field 1A	Maize
Mid field 1B	Sweet potato, wheat
Mid field 2A	Maize
Mid field 2B	Sweet potato
Mid field 3	Barley
Outfield A	Maize
Pasture	Unimproved pasture

Using the IMPACT DST to optimize the farm for income generation the farmer can make a total of 3,300 Birr (approx. USD388) but as you would expect from an optimization model it chooses the most profitable crop and turns the whole farm over to this enterprise, in this case maize (Table 41). Whilst this was known before running the DST, this was done with the farmer group to show them what would happen if is this was their only production goal. The idea was not to suggest this to them but to start discussions, and as expected this started lots of discussion, once the farmers had stopped laughing at the researchers for suggesting such an impractical future scenario.

Table 41. Income optimized scenario of the medium wealth category farmer in Areka, Ethiopia.

Plot	Enterprise
Homestead	Potato, wheat
Mid field 1A	Maize
Mid field 1B	Maize
Mid field 2A	Maize
Mid field 2B	Maize
Mid field 3	Maize
Outfield A	Maize
Pasture	Potato, wheat

The discussion that followed was then about which crops were needed for food security, which for producing livestock feed, which would generate income and in which plot on the farm to grow these crops (Table 42). At the end of the discussion the agreed future scenarios would produce food security and an income of 2,700 Birr (approx. USD318). Whilst this was less than the optimal scenario, this resulted in increased income and maintained many of the food security and livestock options.

Table 42. Farmer optimized production preferences for the medium wealth category farmer in Areka, Ethiopia

Plot	Enterprise
Homestead	Enset, coffee, kale, sweet potato, maize
Mid field 1A	Maize
Mid field 1B	Maize
Mid field 2A	Potato, wheat
Mid field 2B	Maize
Mid field 3	Potato, wheat
Outfield A	Potato, wheat
Pasture	Pasture

Testing and development of prototype DS tool on-farm in East and Southern Africa by project partners (NARES, NGO's, IARC's, farmers)

As mentioned previously this project built on existing work by ILRI that had gone a long way to developing the DST. This project focused on improving this and linking in the soil-crop simulation modeling component. The DST was completed after the first 18 months of this project.

Once it was completed the DST was tested in preliminary meetings with researchers and farmers in Tanzania, Ethiopia and Zimbabwe, as well as in Kenya and Ghana, through existing funded projects to ILRI. An example of its testing and development follows:

Lushoto, Tanzania example

The first visit to the farmer groups in Lushoto collected the data required to parameterize IMPACT and the household model. Three wealth categories had been previously identified in on-going work and data for each wealth group was collected and entered into the DST. A follow-up visit then presented their data back to the group, including their current production enterprises, food security situation, nutrient balance and income (Photo 5). During this feedback and further discussion to capture the current situation and future and alternative scenarios changes in their land allocation were discussed to allow them to achieve food security (Figure 33). As we saw in the Ethiopia example above, this was not to make them change their farming practices but to stimulate discussion on options that they had and which one would fit best given their attitudes to risk and vulnerability and to the demands on human and livestock feed and income generation.

Photo 5: Feedback of DST scenarios to farmers in three different wealth categories n Lushoto, Tanzania.

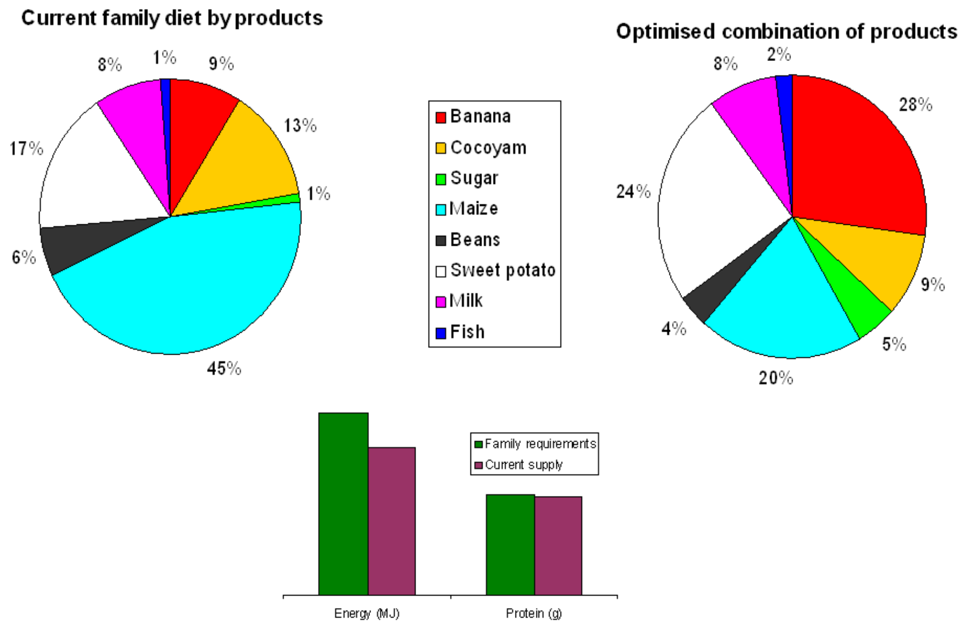
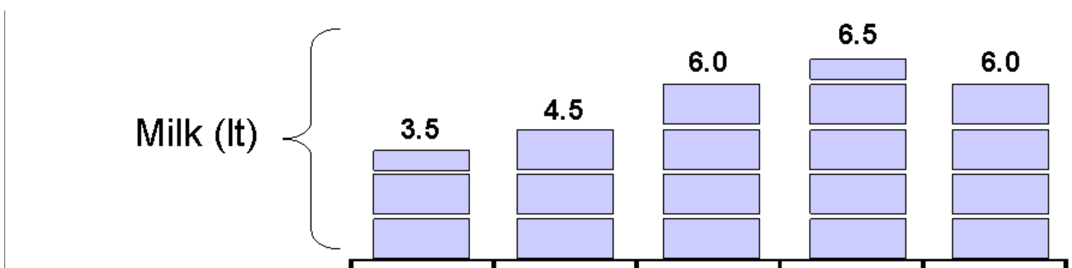


Figure 33. Comparison of current and future contribution of different crops to food security.

This first step allows farmers to see what changes are needed to be able to produce enough products to achieve food security from their farms. In many cases this is not possible and food security can not be achieved from on-farm production. In other cases the changes proposed are just not feasible, as some land needs to be maintained for livestock production or the farm has no money to invest in expanding production activities. Figure 34 shows how the RUMINANT model, as part of the DST, can be used to design ruminant diets for achieving different milk yields and how much of each feed is needed. These options, along with food security allow the group discussions to evaluate many options to find the best way forward. In another funded project run by ILRI in Kenya, farmers are using this approach to change on-farm livestock feed production and diets composition for increasing milk production.



Maize stover	2 kg	1.5 kg	2.5 kg	2.5 kg	2 kg
Napier grass	3.5 kg	2 kg			
Desmodium sp.			2 kg	2 kg	
Maize bran					
Banana leaves/pseud	2 kg	2 kg	2 kg	3 kg	2 kg
Roadside grass					1.5 kg

Figure 34. Use of RUMINANT model for designing ruminant livestock diets in Tanzania.

A critical area that was newly approached in this project was the inclusion of labor in the trade-off analysis that was conducted for achieving food security or in increasing income. Labor was detailed by production activity and by sub-activity (e.g. land reparation, planting, harvesting) in these activities to include the impact of changes on labor demands and cost.

Murewa, Zimbabwe example

In the project activities in Zimbabwe profit and labor costs were explored in relation to potential options for use or changes in targeting of inputs to the farming system. The example given here shows income and labor requirements calculated for two farmers, poor (Table 43) and wealth (Table 44). In these two examples for Zimbabwe they contain scenarios where fertilizer is free which is a reflection of access some farmers have to free inputs through NGO programs in the project area. These scenarios and analysis helps our understanding of where different types of farmers are now, where they can go and more importantly, what constraints do they have to achieve this. We must realize that not all farmers have the resources to purchase inputs or hire labor. Some don't want to hire labor but would rather invest in other farming activities or purchase other household priority items or invest in their children's education.

Table 43. Potential scenarios and implications for income generation and labor requirements for a poor farmer in Murewa, Zimbabwe.

Scenario description	Profit US$	Labor deficit (man-days)
Baseline		
1. Baseline scenario - diet at 70% WHO req.	-7	3
2. Baseline scenario - diet at 100% WHO req. (free fertilizer)	-19	3
3. Baseline scenario - diet at 70% WHO req. (fertilizer cost incl.)	-13	3
Optimized Scenario		
4. Optimized scenario - grain crop plots open (free fertilizer)	87	211
5. Optimized scenario - grain crop plots open (fertilizer cost incl.)	81	211
Explorative optional scenarios - distribution of fertilizers (fertilizer cost incl.)		
6. All fertilizer in plot 1 (Data from APSIM)	21	3
7. Fertilizer distributed equally in plots 1&2 (Data from APSIM)	40	29
8. Scenario 7 with 50% weeding in plot2	26	13
9. Fertilizer inputs distributed equally across plots 1,2&4 (Data from APSIM)	23	56
10. Scenario 9 with 50% weeding in plots 2&3	10	26
Explorative optional scenarios - legume intensification		
9. Expand area under groundnut to plot 4 (fertilizer distributed in plots 1&2)	72	46

Using this DST helps us work with partners and farmer groups to evaluate their options and to allow them to be able to decide which option suits them best, given their production objectives and perceptions of risk.

These partner and farmer group meetings proved critical in leading to improvements to simplify the data entry formats, addition of new data collection needs and a better understanding of what researchers and farmers wanted from the DST. The evolution and changes made in the subsequent two years are too many to mention but led to a total redesigning and remodeling of the DST. The resulting product has now been Beta tested in all sites. The IMPACT systems characterization database which includes the sub-models for calculating food security, farm economics and nutrient balances, with a user manual, has now been released on CD and through the internet.

Table 44: Potential scenarios and implications for income generation and labor requirements for a wealthy farmer in Murewa, Zimbabwe.

Scenario description	Profit US$	Labor deficit (man-days)
Baseline		
1. Baseline scenario - diet at 70% WHO req.	172	43
2. Baseline scenario - diet at 100% WHO req.	147	43
Optimized Scenario		
3. Optimized scenario - grain crop plots open for best option	448	153
Explorative optional scenarios - distribution of fertilizers (fertilizer cost incl.)		
4. All fertilizer in field closets to homestead (Data from APSIM)	95	18
5. Fertilizer distributed equally in plots 1&2&6 (Data from APSIM)	119	99
6. CpD+AN field 1; manure+AN field 3 (Data from APSIM)	169	90
7. manure+AN field 1; CpD+AN field 3 (Data from APSIM)	163	56
Explorative optional scenarios - legume intensification		
8. Resized plots: Expand groundnuts to plot1 (close to homestead)	165	198
9. Resized plots: Expand groundnuts to (outfield)	147	200

One problem encountered was the use and release of the DST with the optimization model installed. This problem is due to that fact that the multiple goal linear programming software is a commercial version and needs licensing, at a cost of several thousand dollars a copy. Discussions have concluded with the owning company and they have agreed to provide a run-time version for the DST at no charge. For this to be useful a final version of the linear programming software in the DST needs to be completed and this is taking more tie than envisaged. The challenge is not the programming but that every time we hold training course on the DST more ideas arise that partners want incorporated. Due to the endless nature of these requests, we have decided that by the end of 2004 to produce a run-time version and release the fully functioning DST on CD, with a users manual.

Participatory models in fostering farmer innovation to minimize trade-offs and induce win-win benefits: The case of Organic Resource Management

Tilahun Amede

Tropical Soils Biology and Fertility Institute of CIAT

This work is a continuation of earlier investigations which revealed that there is very strong trade-off for the limited organic biomass (i.e. crop residue, manure, stubble, weeds, grasses and underground biomass) at farm and landscape scales among various uses namely, as a cooking fuel, as livestock feed, as cash generation enterprise and as soil fertility restorer. And yet, the amount of organic biomass in the system is very much limited to satisfy these different needs, which are all probably important but the household decision is made based on priority needs. The objective of this work were to understand farmer experimentation processes to overcome biomass constraint in the system, to document farmer innovations towards solving the problem and to develop farmer-friendly tools & guides to improve farmer-community understanding of their farm & landscape systems for identification of niches. The major steps considered to date were: a) Participatory mapping of the current sources of biomass at plot, farm and mini-watershed-level including crops, forages, trees, valley bottoms, homestead crops and other niches b) participatory estimation of biomass yield per time and space in selected farms c) Monitoring resource flows and production fluctuations at household level in selected farms d) Participatory identification of possible niches for growing more biomass in the system, e.g. integration of high biomass producing, promiscus type legumes, (e.g. Climbing beans, Soy beans) and fast growing and browsing resistant forages (e.g. napier grass).

4.6 Quantify benefits of ecosystem services from farm to community level

4.7 Determine livelihood impacts of resilient production systems

TSBFI-Africa

Published Work

Advancing human nutrition without degrading land resources through modelling cropping systems in the Ethiopian Highlands

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Food and Nutrition Bulletin, Boston. In Press (December, 2004).
Food shortage in sub-Saharan Africa is generally considered a function of limited access to food, with little thought to nutritional quality. Analyzing household production of nutrients across farming systems could be valuable in guiding the improvement of those systems. An optimization model was employed to analyze the scenario of human nutrition and cropland allocation in enset (Enset ventricosum)/root crop–based and cereal-based systems of the Ethiopian Highlands. The type and amount of nutrients produced in each system were analyzed, and an optimization model was used to analyze which cropping strategies might improve the nutritional quality of the household using existing resources. Both production systems were in food deficit, in terms of quantity and quality of nutrients, except for iron. The energy supply of resource-poor households in the enset/root crop-based system was only 75% of the recommended daily allowance (RDA), whereas resource-rich farmers were able to meet their energy, protein, zinc, and thiamine demands. Extremely high deficiency was found in zinc, calcium, vitamin A, and vitamin C, which provided only 26.5%, 34%, 1.78%, and 12%, of the RDA, respectively. The RDA could be satisfied if the land area occupied by enset, kale, and beans were expanded by about 20%, 10%, and 40%, respectively, at the expense of maize and sweet potato. The cereal-based system also had critical nutrient deficits in calcium, vitamin A, and vitamin C, which provided 30%, 2.5%, and 2% of the RDA, respectively. In the cereal system, the RDA could be fully satisfied by reducing cropland allocated to barley by about 50% and expanding the land area occupied by faba beans, kale, and enset. A shift from the cereal/root crop-dominated system to a perennial-enset dominated system would decrease soil erosion by improving the crop factor by about 45%. This shift would also have a very strong positive impact on soil fertility management. However, any policy suggestions for change in cropland allocation should be done through negotiations with households, communities, and district stakeholders.

On-going work

Contemporary patterns of land use and land use change in contrasting areas of western Kenya S.E. Carter[1], J.J. Ramisch[2], E.L. Crowley[3], C. Mulogoli[2]
[1] IDRC, Ottawa, Canada; [2] TSBF-CIAT; [3] FAO, Rome
Paper in preparation for Land Use Policy

This paper examines the changes that have taken place in land use this century in two areas of Western Kenya in order to address a number of issues related to agrarian change in African farming systems. Our practical concern is to contribute to understanding the context and dynamics of some of farmers' current land management practices in the region. Our work, conducted in the context of a programme of research on soil fertility, focuses on changes in the dominant, cultivated elements of the landscape of Western Kenya. To this end we attempt to identify the more dynamic crop components of two of the main farming systems, in order to suggest the implications that contemporary change may have for resource managers and for an applied research agenda in support of their efforts. This is particularly important in W. Kenya since there is at present considerable debate over the relationship of agrarian change to change in soil fertility in the region.

In addition we wish to make a modest contribution to the theoretical debates on African agrarian change. Thinking in the 1990s has centred around two stances. Firstly refinements of Boserup's argument that demographically -driven agrarian change is leading to an intensification of farming systems as farmers respond positively to increased market opportunities. The second is more critical, providing a radical interpretation of change centred on power relations between institutions or between social groups or men and women. Berry (1993) attempts a synthesis of much of this work, and contributes a portait of dynamic complexity, of similar processes of social change unfolding upon very different historical and geographical backgrounds and with largely unpredictable results.

We address three questions that have some bearing on these practical and theoretical debates:

1. What are the causes of different paths of land use change in W. Kenya, be they social, economic, ecological or historical processes? To answer this we contrast Kabras and Maragoli, two areas of Kenya's Western Province that are often perceived as ethnoculturally, economically and environmentally similar but where very different paths of land use change have been taken. We think it is useful and of benefit to scientists concerned with social and environmental change in Western Kenya to try to unravel the reasons for these differences.

2. In recent years, how have farmers (men, women, "households", or wider "communities") reacted, in their choices between specific crops and between on-farm and off-farm livelihood strategies, to forces external and internal to their agro-social systems? The two study areas provide a useful comparison and contrast of farmers' strategies to cope with change, that have led to different patterns of land use. They also provide a useful comparison with some of the findings on agricultural intensification of Tiffen et al (1994) in another part of Kenya, particularly the latters' claims regarding the generality of the processes of intensification.

3. What is the relationship between changing patterns of land use and labour allocation and the maintenance of land quality? A good deal is known about the general changes that have taken place in the allocation of labour to different crops and activities within Kenya, in response to political-economic and social change during the colonial and post-colonial periods. However, Berry (1993) argues that more recent structural changes have brought about a further decline in rural people's access to labour in many parts of Sub-Saharan Africa. For example, Mackenzie (1993, 1995), writing of Kenya, suggests that structural change and increased demands on women' labour have reduced their ability to maintain soil fertility in the face of increasingly pressing short term goals. Therefore we attempt to shed some light on the relationship between land use change (as reflected in choice of crops), male and female labour allocation and soil fertility management in Western Kenya.

In order to answer these questions we examine archival, oral historical and other documentary evidence for the period from the late Nineteenth Century until after Independence. This historical analysis of past changes in resource management is important to an understanding of contemporary conditions because of the long continuity of many processes that affect farmers' management decisions. For the post Independence period we draw on additional sources of remotely sensed land use data and survey data collected by us in a random sample of 700 households (*muunzu)* in 1995. We emphasise the period from the mid 1980s to mid 1990s in our analysis, both to identify issues of relevance for contemporary applied research in agriculture and natural resource management in the region and to contribute new material to the current debates on agrarian change.

4.5 OUTPUT 5. Sustainable land management for social profitability developed, with special emphasis on reversing land degradation

Rationale

The economy of low income countries need to grow steadily at a rate of 3.6% annually in order to achieve the Millennium Development goal of reducing by half the global population living with less than 1US/day by 2015. Agriculture is an essential component for the environmentally and socially sustainable development of developing countries. Balancing higher agricultural productivity and access to markets with the maintenance of the resource base and the quality of the environment is a major challenge that requires integration of knowledge and policies across scales ranging from farm to landscape level.

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

Agriculture needs economic soil management practices that provide sufficient food and yet maintain environmental stability, ecological integrity, and the quality of essential resources. Strategies for sustainable land management include conserving essential soil components, minimizing erosion, balancing production with environmental needs, and making better use of renewable resources. In this regard, soil health is a major indicator of sustainable land management. Criteria for indicators of soil health are useful in defining ecosystem processes and sensitivity to managements and climatic variations and in integrating physical, chemical and biological soil properties. Land users and decision makers need to use those criteria for implementing sustainable land management practices.

Interest in the quality and health of soil has grown with the recognition that soil is vital not only to production of food and fiber, but also for the smooth functioning of the ecosystem and overall environmental stability. Soils play a central role for the provision of ecosystem services such as regulation of water quality and quantity, biodiversity, carbon storage and net fluxes of greenhouse gases to the atmosphere. Appropriate soil management could result in enhanced provision of such services. However, reliable and cost effective assessment of such services at farm and landscape level and the development of mechanisms to compensate farmer communities that manage the soils, remain to be major challenges. TSBF-CIAT intends to contribute to fill this gap in knowledge through partnerships with other CIAT projects and with regional Consortia (AFNET, MIS, CONDESAN, the Amazon Initiative).

Projections indicate that eastern and southern Africa, and Central America will be critically short of water in the coming decades. Extending TSBF-CIAT's research agenda to address water issues to these regions is required. The new proposals approved by the Water and Food Challenge Program for the Volta basin in West Africa and on the Quesungual slash/mulch agroforestry system in Central America offer the opportunity to address constraints related to water and its interaction with soil fertility, soil erosion and other ecosystem services.

Milestones

- By 2007, identification, characterization, and monitoring of degraded lands available for at least 2 regions.
- By 2008 methods for socioeconomic evaluation/valuation of ecosystem services for trade-off and policy analysis used, at least in 2 humid and 2 sub-humid Agro-ecological zones.
- By 2010, 30% of partner farmers in pilot sites used SLM options that increase productivity and arrest resource degradation

Highlights

- Main factors influencing maize production in the Quesungual agroforestry system included altitude of farms above sea level, phosphorus fertilizer input and the density of the tree component.
- Showed that the high potential of the NIRS (Near Infrared Reflectance Spectrometry) for evaluating soil quality in large areas, rapidly, reliably and economically, thereby facilitating decision-making with respect to soil management and conservation
- Found that the savannas from Colombia and Venezuela have an estimated total carbon stock of 3.1 Pg C in the top 30 cm of the soil. Projected intensification of agriculture, livestock and forestry in the region in the next two decades could result in a net increase of 160 Tg of C in the soil stocks.
- Diverse land use systems in the Fuquene watershed, result in drastic differences in the degree of limitation to root growth. Degraded land show extremely high values that virtually impede any plant establishment and growth.

5.1 Identify & characterize biophysical, social & policy niches where different technologies to address land degradation in the landscape will fit

On-going Work of AfNet

I. Long term trials

The objective of these network activities is to develop and implement management options that both mitigate soil degradation, deforestation and biological resource losses and enhance local economies while protecting the natural resource base.

In 2003, trials were established at four representative benchmark sites in some important agro-ecological zones of Niger (West Africa) (Table 45). On-station and on-farm researcher managed and farmer-managed trials were carried out. Through the Rockefeller grant in West Africa, a vital link was established between TSBF and collaborating institutions in West Africa especially ICRISAT.

1. Long-term soil fertility management trials

a) Long-term management of phosphorus, nitrogen, crop residue, soil tillage and crop rotation in the Sahel

Since 1986 a long-term soil fertility management was established by ICRISAT Sahelian Center to study the sustainability of pearl millet based cropping systems in relation to management of N, P, and crop residue, rotation of cereal with cowpea and soil tillage. The data in Table 46 gives the main treatments in this trial. In this split-split-plot design the split-split plot consisted of crop residue application or no crop residue application consisting of leaving half of the total crop residue produced in the plot and the sub-sub plot was with or without nitrogen application.

Table 45. Network collaborative trials in Niger (West Africa), 2003.

Type of Trials	Site
Long-term operational scale research	Sadore
Long-term cropping system	Sadore
Long-term crop residue management	Sadore
On-farm evaluation of cropping systems technologies	Sadore,Karabedji Gaya
On-farm evaluation of soil fertility restoration technologies	Karabedji, Gaya
Comparative effect of mineral fertilizers on degraded and non degraded soils	Karabedji
Fertilizer equivalency and optimum combination of low quality organic and inorganic plant nutrients	1. Banizoumbou, 2.Karabedji, 3. Gaya
Monitoring nutrient budget	Banizoumbou
Biological nitrogen fixation	Banizoumbou, Gaya
Corral experiment (demonstration)	Sadore

Table 46. Main treatments used in the Integrated Soil Fertility Management trials at Sadore

1= Traditional practices
2= Animal traction (AT) +no rotation +Intercropping + P
3= Animal traction (AT) + rotation +Intercropping + P
4= Hand Cultivation (HC) +no rotation +Intercropping + P
5= Hand Cultivation (HC) + rotation +Intercropping + P
6= Animal traction (AT) +no rotation +Pure millet + P
7= Animal traction (AT) + rotation + Pure millet + P
8= Hand Cultivation (HC) +no rotation + Pure millet + P
9= Hand Cultivation (HC) + rotation + Pure millet + P

The traditional farmers' practice yielded 73 kg/ha of pearl millet grain whereas with application of 13 kg P/ha, 30 kg N/ha and crop residue in pearl millet following cowpea yielded 1471 kg/ha of pearl millet grain (Table 47). These results clearly indicate the high potential to increase the staple pearl millet yields in the very poor Sahelian soils.

Table 47. Effect of fertilizers, soil tillage, crop residue, cropping system on pearl millet grain yield; Sadore 2003 cropping season.

Treatments	Pure millet grain yield (kg/ha)							
	- Rotation				+ Rotation			
	- Crop residue		+ Crop residue		- Crop residue		+ Crop residue	
	-N	+N	-N	+N	-N	+N	-N	+N
Traditional	73	86	83	119				
Phosphorus + HC	299	818	479	909	341	699	851	1212
Phosphorus + AT	526	836	670	1028	870	1128	1048	1471

HC: hand cultivation, planting on flat; AT: Animal traction, planting on ridges

b) Long-term management of manure, crop residues and fertilizers in different cropping systems

Since 1993 a factorial experiment was initiated at the research station of ICRISAT Sahelian Center at Sadore, Niger. The first factor was three levels of fertilizers (0, 4.4 kg P + 15 kg N/ha, 13kg P + 45 kg N/ha), the second factor was crop residue applied at (300, 900 and 2700 kg/ha) and the third factor was manure applied at (300, 900 and 2700 kg/ha). The cropping systems are continuous pearl millet, pearl millet in rotation with cowpea and pearl millet in association with cowpea. The analysis of variance data indicate that fertilizer; crop residue and manure application resulted in a highly significant effect of both pearl millet grain and total dry matter yields. Fertilizer alone account for 47% in the total variation of the dry matter whereas manure account for 17%. Although some interactions are significant they account for les than 2% in the total variation.

For pearl millet grain, the application fertilizer, manure, crop residue and cropping systems alone account for 66% of the total variation. The data in Figure 35 illustrate the response of pearl millet grain to crop rotation and different input of organic and inorganic fertilizers. The farmer's practices yield 335 kg/ha; the application of 13 kg P and 45 kg N/ha yielded 834 kg/ha but when these mineral fertilizers are combined with 2.7 t/ha of manure or crop residue in rotation with cowpea, yield of 1584 kg/ha can be achieved. The N and P fertilizer value of manure and crop residue is 45 and 13 respectively and the N and P equivalency of manure is 87% and 65% for crop residue (Table 48). The high values of fertilizers equivalency of manure and crop residue suggest that the organic amendment have beneficial roles other than the addition of plant nutrient such as addition of micronutrients and better water holding capacity.

Table 48. Fertilizers equivalency of manure and crop residue at Sadore, Niger, 2003 cropping season.

Parameters	Grain (kg/ha)	Total dry matter (kg/ha)
Absolute control	335	1367
% N in manure	1.6	1.6
% P in manure	0.32	0.32
% N in crop residue	0.71	0.71
% P in crop residue	0.03	0.03
Yield at 2.7t/ha of manure in continuous cropping	775	2419
Yield at 2.7 t/ha of crop residue in continuous cropping	478	1537
Equivalent N and P of the manure	45	29
Equivalent N and P of the crop residue	13	8
Fertilizer N and P equivalency of manure (%)	87	56
Fertilizer N and P equivalency of crop residue (%)	65	40

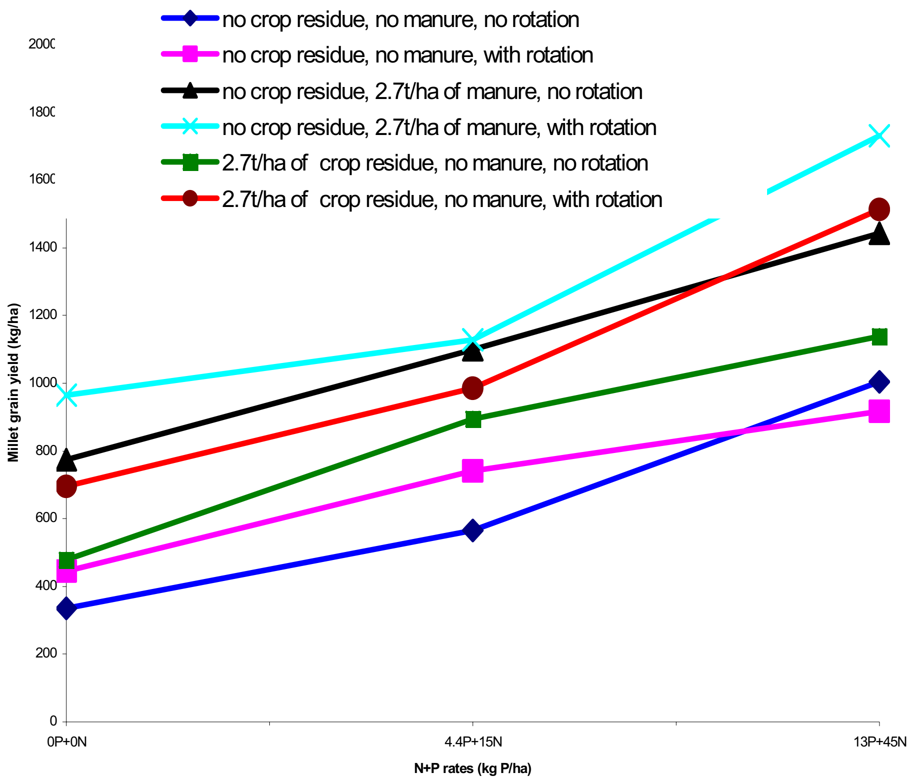

Figure 35: Effect of different N and P rates on pearl millet grain yield, Sadore, Niger, 2003 rainy season.

In addition, the release of nutrient with mineralization over time can match more the plant demand and this will result in higher nutrient use efficiency from the organic amendments. It is also well established that the application of organic amendments can reduce the capacity of the soil to fix P and then increase P availability to plant.

Another crop residue (CR) trial established since 1982 show a large cumulative effect on the soil (organic carbon, protection against erosion…) over these years. Sole application of CR increased the millet grain yield from 253 kg/ha to 833 kg/ha and the millet total dry matter yield from 1865 to 4618 kg/ha (Table 49).

Table 49. Effect of fertilizer and crop residue on pearl millet and cowpea at Sadore, 2003 rainy season

Treatment	Grain yield (kg/ha)		TDM (kg/ha)	
	Millet	Cowpea	Millet	Cowpea
1=Control	253	33	1865	200
2=crop residue (CR)	833	96	4618	1158
3=Fertilizer (F)	568	71	2800	658
4=CR+F	1355	54	7089	1742
SE	96	20	280	132
CV	25%	62%	14%	28%

The data in Table 50 give the rainfall and chemical characteristics at study sites in the Sahel. These soils are acidic and inherently low in nutrients with ECEC of less than 1 c mol/kg for all the sites except Gaya where the organic carbon is slightly higher and an ECEC of 1.3 c mol/kg. The data in Figure 36 on phosphorus sorption isotherm clearly indicated that most of the soils have very low capacity to fix P due to their sandy nature.

Table 50: Annual precipitation (2003) and soil characteristics for selected villages.

Sites	Rainfall Mm	pH KCl	C.org (%)	P-Bray1 (mg/kg)	Ca^{2+} Cmol/kg	ECEC Cmol/kg	N_{min} (mg/kg)
Sadore	534.6	4.3	.12	2.0	0.3	1	3
Banizoumbou	510.4	4.4	.12	1.5	0.4	0.8	5
Karabedji	533.25	4.2	.16	1.9	0.2	0.8	4
Goberi*	450	4.1	.16	1.7	0.2	0.8	2
Gaya	883.5	4.2	.33	2.5	0.4	1.3	9

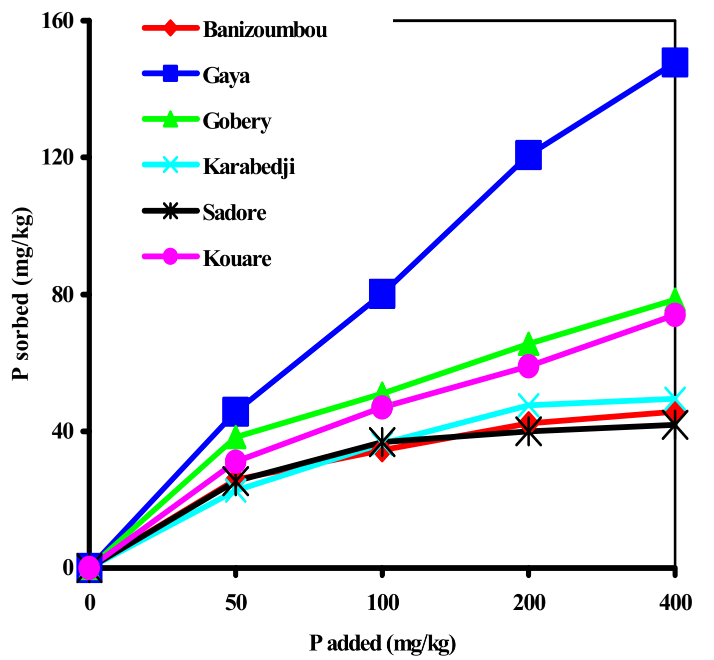

Figure 36. Phosphorus sorption isotherms of soil samples from benchmark sites in Niger and Burkina Faso.

As manure was used in most of the trials in combination with mineral fertilizer, a systematic chemical characterization of the manure used at the different sites was undertaken and the data are reported in Table 51.

Table 51. Characterization for N, P, K and polyphenols of the organics materials used for the trial in each site.

Site	Manure origin	Total N (%)	Total P (%)	Total K (%)	Polyphenols (%)
Banizoumbou	Composite	1.6	0.32	0.75	0.64
Karabedji	Composite	0.26	0.12	0.45	1.02
Gaya	Composite	2.6	0.35	0.80	0.75

Those data will be used to determine the fertilizer equivalencies of different manure sources for nitrogen and phosphorus. The nitrogen and phosphorus levels in the manure were very low and N levels varied from 0.26% to 2.6% and the P levels varied from 0.12% to 0.35%.

TSBFI-Latin America

Completed work

Main factors influencing maize production in the Quesungual agroforestry system in Southern Honduras: An exploratory study

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The objective of this study was to make a systematic description of Quesungual by identifying key factors influencing system performance as well as an assessment of the critical variables influencing maize production. In order to describe the farming system, in which the Quesungual is used, information was collected from 62 farms emphasizing characteristics of the farm household, land use, input use, tree components and farmer perceptions about the benefits they get from this agroforestry system. In a second phase, twenty farms were selected to carry out an analysis of the critical variables affecting maize production in Quesungual fields. In order to select these study farms, the original 62 farms were classified in terms of farm size and land use. Detailed information regarding farm household characteristics and management with emphasis on maize fields and sampling of soils and mulch, as well as measurements of crop yield, was collected through resource flow maps, transect walks, questionnaires, sampling and direct measurements in the maize fields.

The 62 farms studied had land holdings ranging from 0.35 ha to 18 ha. Farmers in the area have limited education, with 1 to 4 years of primary school, and a few never had access to any kind of formal education. The majority of the farmers in the sample have low wealth levels (55%). Forty seven percent (47%) of farmers worked with extension services and 50% had access to credit. The credit is used for buying fertilisers and herbicides. Off-farm work as labourers in other farms is the main source of income. The main agricultural activity in the area is the production of maize, beans and sorghum. Other crops such as coffee, sugarcane, and banana are also planted in limited quantities. Cattle ranching is also an important activity specially at lower altitudes of the study region. Input use is diverse and dependent on resource endowment as well as on perceptions regarding soil fertility. At farm level, 84% of the farmers used fertilisers (urea + compound fertiliser) for basic grain production. Seventy nine percent of the farmers reported using herbicides, and 43% of the farmers used insecticides. Nevertheless, none of the farmers used fungicides. External input use is generally restricted to maize crops and to a lesser extent to bean crops. Nevretheles, insecticides are almost exclusively used for bean production due to pest problems. Almost no inputs are applied to sorghum fields. The role of cattle on nutrient management is generally not consciously recognised by farmers.

Management of Quesungual fields regarding the tree component is influenced by several factors: i) original abundance of trees in the secondary forest at the moment of pruning and conversion to QSMAS, ii) the farmers' local knowledge and iii) the production objectives. Secondary forest tree diversity is reduced following pruning as well as death of some trees unable to tolerate repeated pruning. There is strong preference for timber species especially in the case of timber trees and the naturally regenerating tree categories. In fact, the most abundant species is the timber tree Cordia alliodora, representing 22% of the total frecuency. The remaining species are mainly used as Pruned trees. Pruned trees dominate the tree component because of their high density and consist mainly of weedy species. Timber tree densities had a mean of 304 ± 31 trees ha^{-1}, ranging from 18 to 1503 trees ha^{-1}. Mean densities of Pruned trees are 877 ± 55 trees ha^{-1}, although the range varying between 141 trees ha^{-1} up to 2,405 trees ha^{-1}. Naturally regenerating trees densities at field level are 232 trees ha^{-1}, with a wide range from 0 to 867 trees ha^{-1}. (Table 52).Farmer perceptions with respect to the tree component are related to the benefits of the trees rather than negative effects.

In general, soil variables evaluated had limited power to explain yield variability when considered individually as well as in multiple regression. Multiple regression analysis showed that the main factors influencing maize production were altitude at farm location (Figure 37), P fertiliser input (Figure 38) and Timber trees (figure 39), although the later had a negative influence possibly due to competition. The influence of other soil and management factors was less or not statistically significant. However, an analysis of P use efficiency helped to clarify the importance of labour and timing, and how it could be related to farmer resource endowment. Farmers whose labour availability was limited due to shortage or competing activities had low labour inputs or sowing dates far from the optimum, accordingly the efficiencies of P use were low.

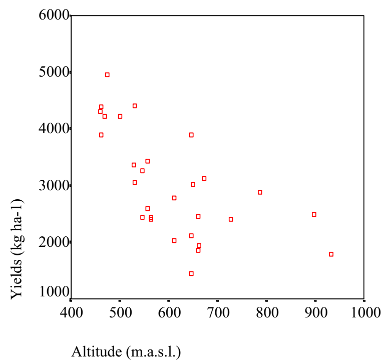

Figure 37. Yields (kg ha^{-1}) of maize, plotted against altitude (meters above sea level), in Quesungual fields in Candelaria, Honduras. R = -0.63 (p<0.001); N = 29 fields

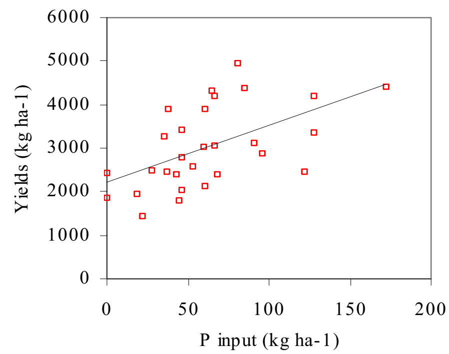

Figure 38. Yields (kg ha^{-1}) of maize and P supplied by fertilisers (kg ha^{-1}) in Quesungual fields in Candelaria, Honduras.
R = 0.55 (p<0.001); N = 29 fields

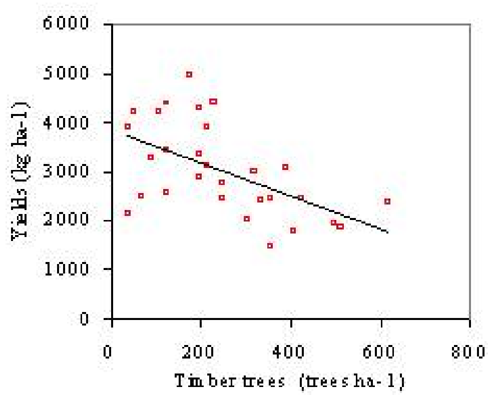

Figure 39. Maize yields (kg ha^{-1}) and Timber tree (TT) density (trees ha^{-1}) of Quesungual fields in Candelaria, Honduras. Dashed line shows the maximum tree density at which there is not reduction of maize production.

Farmers adopting the Quesungual system in the sample studied could be divided in two main groups: a) small and medium farms whose main orientation of production is grain for consumption or sale of surplus; b) farms with greater capital and land resources where production is oriented towards cattle production and diversification to other products. However, within these two farmers groups there is variability in the management of maize crops. This subdivision led to a further division generating a total of five farm types, three in the group of small farmers: Farm type 1) income from remittances; Farm type

2) income from off-farm work (agricultural work in other farms); and farm type 3) income derived from off-farm work and sale of grain surplus. Larger farms were divided in two groups: Farm type 4) income derived from cattle and cash crops or sale of small animals, and Farm type 5) income derived from off farm employment (non-agricultural work, for instance carpenters, guards) and cattle. In general the group of small farmers is composed of land holdings smaller than 5 ha, while farm size of the large farms is -oin average 8 ha. Table 52 show the characteristics for each farm type.

This exploratory study of the Quesungual Slash and Mulch Agroforestry System has been important to identify some key factors influencing system performance. It has also been important to help us revise our original research approach and open up many new interesting research questions.

Table 52. Ranges of farm household characteristics, land use, input use, tree component and crop management of the five farm types found in farms at Candelaria. Classes have been defined on the basis of farm size, income generating activities and total income.

	Small farms			**Cattle high income farms**	
Farm type	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	**Farm 5**
N	3	6	4	4	3
Intrinsic factors					
Slope (%)	33 – 73 b	46 – 95	35 – 56	38 – 54	28 –74
Criteria of selection					
Farm size (ha)	2 – 3.5	1 – 3	3 – 6	4 –14	3 – 13
Income generating activities [a]	R, SC & SF	OFW, SP,	R, OFW,	R, OFW,	OFW, CR
Income (lempiras year^{-1})	1590-1700	1490-10838	3190-9848	8080-24936	13200-80000
Farm household					
Family size (# persons)	3 – 8	2 – 11	4 – 7	4 – 9	7- 10
Labour availability (# workers	0.8-1.5	1 – 2.5	1. 4.5	1.5 – 5	1 – 3
Wealth class	Low	low - middle	low - middle	middle -	Middle –
Land Use					
Fallow (% from used land)	12 – 57	0 – 41	17 – 52	1 – 50	27 – 63
Basic grains (% from used land)	38 – 41	46 – 98	35 – 50	19 – 70	12 – 29
Other crops (% from used land)	5 – 19	0 – 17	0 –13	3 – 13	1 – 6
Pastures (% from used land)	-	0 - 25	-	8 – 59	2 – 52
Productivity [b]					
Maize - Milpas (kg grain ha^{-1})	0.1 – 0.4	0.6 – 1.9	1.1 – 2.9	0.7 – 1.4	1.1 – 1.6
Sorghum – Milpas (kg grain ha^{-1})	0.5 – 1.2	0.5 – 1.7	0.3 – 1.2	0.4 – 1.3	
Bean fields (kg grain ha^{-1})	0.1 – 0.4	0.4 – 1	0.1 – 0.4	0.3 – 0.9	0.3 – 0.5
Total bulk production[c] (kg farm)	1.7 – 2.5	1.8 – 2.9	1.9 – 4.6	2.2 – 3.9	1.5 – 2.1
Management factors					
Labour input (person-day ha^{-1})[d]	67 – 131	47 – 145	89 – 124	44 – 101	69 – 97
N input (kg N ha^{-1})[d]	60 – 257	19 – 120	96 – 159	72 – 123	50 – 196
P input (kg P_2O_5 ha^{-1})[d]	28 – 128	19 – 81	36 – 119	21 – 96	68 – 128
Herbicide input (kg a.i. ha^{-1})[d]	1.1 – 7.2	0.9 – 6.6	0.9 – 4.3	0.6 – 2.7	0.9 – 2.4
Sowing date (coefficient)[f]	0.09 – 0.59	0.09 – 2.12	0.34 – 0.77	0.09 – 1.26	0.09 – 1.26
Plant density –maize (plants ha^{-1})[e]	22200-34000	29300-42100	32900-42200	28200-46200	35000-42600
Quesungual factors					
Mulch (kg DM ha^{-1}) [e]	9.6 – 10.8	6.1 – 15.2	6.6 – 12.4	6.2 – 11.4	6.1 – 12.6

Coverage (%)[e]	58 – 68	37 – 75	48 – 67	51 – 74	51 – 72
Natural Regeneration (trees ha^{-1})	18 – 71	106 – 460	159 – 336	0 – 230	124 – 601
Pruned Trees (trees ha^{-1})	1132 – 1609	637 – 1698	637 – 1353	336 – 1574	141 – 1415
Timber Trees (trees ha^{-1})	71 – 318	141 – 495	168 – 309	53 – 292	195 – 619
Productivity					
Yield (g $plant^{-1}$)	98 – 124	51 – 129	88 – 117	51 – 98	66 – 96
Yield (kg ha^{-1})	2.5 – 4.2	1.8 – 5	2.9 – 4.3	1.4 – 4.2	2.4 – 3.4

a Income generating activities are put in order of importance for each farm type (R = remittances, SC = Sells of chickens, SP = Sells of pigs,
SBG = Sell of basic grains, SF = Sells of fruits, SOC = Sells of other crops, OFW = Off farm work & CR = Cattle raising)
b Data based on farmers estimates reported on the resource flow maps during interviews
c Total production includes yields of basic grains, and other crops like coffee, sugar cane, and pumpkins
d Data from resource flow maps (questionnaires)
e Data from sampling during the visits to the farmers (based on measurements)
f Coefficient expressed in standard deviations from the mean sowing date, starting from the beginning of may.

Adoption of new soil conservation technologies in the llanos of Colombia: Arable layer building technology

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Impact Evaluation Project
TSBF-CIAT

As a result of CIAT's collaborative research activities with Corpoica, Pronatta and Unillanos, with financial support from MADR and COLCIENCIAS, a series of soil improvement and conservation practices are available. These practices focus on arable layer building technologies —part of the soil profile that can be modified through a combination of biological and physical management— in soils of the savannas of the Llanos of Colombia. These practices include use of proper crop and pasture rotations in agropastoral systems.

In August 2004, a rapid survey was conducted in order to learn about the adoption of the arable layer building technology (Capa Arable) in farms located in the area of Puerto López - Puerto Gaitán in the llanos of Colombia.

In total, 18 farmers were interviewed, including those that were using and not using the technology. The survey was done using the methodology of semi-structured interviews to groups of producers, technicians and experts of the region, to identify and understand trends and main features of the adoption process.

Results of this survey make reference to technology adoption in early phases, since the first farmers adopted it 4 years ago and the majority of them started adopting it between 1 and 2 years ago. In Table 53 we summarize the main results obtained in the survey and we discuss the major findings.

In general, producers showed great interest in maintaining and improving soils quality, since this practice has a high and rapid payoff in terms of crops and pastures yield. Farmers in the past attempted to establish crops without adequate soils management and used non- adapted pasture and crop germplasm, and consequently experienced large economical failures. In contrast to the previous experiences, utilization of soil conservation methodologies together with the use of improved germplasm have shown significant advantages in productivity and in economic returns to the investments made.

Table 53. Results of the survey on the use of the arable ayer building technology by oproducers in the llanos of Colombia.

Variable	Level
Number of producers interviewed	18
Land Use	
Total Area of farms (ha)	
Mean	883
Range	120-5000
Area under crops (ha)	
Mean	238
Range	0-1100
Area under pastures and other uses (ha)	
Mean	645
Range	0-3900
Area under crops/Total Area (%)	27
Proportion of producers with no crops (%)	28
Most common rotation	Maize-soybean
Most common land preparation method	Vertical tillage with chisel plow

Practices for arable layer building include a vertical corrective tillage using rigid chisels, correction of nutrient deficiencies in soil and sowing of forages and acid soil adapted crops. In some cases, lack of key inputs such as machinery, fertilizers and seeds prevents establishment of crops or timely harvest of crops, which has negative implications for building arable layer and for the economics of the system. There is great interest from the Colombian government and also from the private sector (e.g., poultry) in emphasizing grain production in the savannas of the llanos of Colombia. Some field crops are being established in the farms of poultry farmers to improve feed production in the region. Thus the expansion of field crops in the region is beeing pushed by the poultry sector.

The most frequent rotation is maize in the first semester and soybean in the second. The new rice variety, Line 30, recommended in this technology and that has not been commercially released yet is creating great expectation among farmers due to its high productive potential.

Even though there is clear conscience among producers of the fact that continuous monoculture degrades the soils and provokes greater pest and disease pressure, price variations in crops seem to drive the rotation cycles. High price expectations for soybean in 2004 induced many producers to plant this crop in both semesters.

Many of the farmers that have introduced crops in their farms traditionally have been and continue to be livestock producers. The majority of these farmers interviewed said that they are working with crops to improve soils and to subsequently sow high productivity pastures. Thus it seems that there will be a high demand for new forage cultivars that are being developed by CIAT Tropical Forages Project, as is the case of the new Brachiaria hybrids such as Mulato already in the market.

Productivity gains constitute the principal benefit perceived by those who apply soil conservation practices in the well -drained savannas of the llanos. In general, yields in the first sowing are low, but increase subsequently as a result of soil improvement. With soybean, initial yields are between 1,5 and 1.9 t/ha, and in rare cases reaches 3t/ha. With maize, yields are between 4 to 5 t/ha. It is foreseen that over time crop yields will begin to decline and when this occurs it will be the time to introduce pastures in the rotation.

Since the introduction of crops is new in the Llanos, most farmers interviewed do not have enough clarity on the duration of the crop phase and pasture phase of the rotation. Several of the farmers interviewed consider that between 4 and 5 years of crop rotations is needed before reconverting the land to pastures; other farmers estimate that changing crops to pastures will occur when productivity of the crop starts to decline as a result of soil fertility loss.

Constraints for adopting the arable layer building technology are economic in nature and lack of infrastructure.

Some of the economical constraints have to do with:

1. Low availability of capital associated with inappropriate credit plans.
2. Market price fluctuations of products that generate large income variations.
3. Eventual oversupply of products such as rice, and
4. High cost of inputs and agricultural machinery.

In terms of infrastucture the following limitations were mentioned:

a) Poor roads that increase cost of transportation, and

b) Low quality of seeds sold in the market that results in poor yields and reduced income.

Those farmers who have not introduced crops in their farms mentioned various reasons for not having done so:

a) Land shortage, which is something critical in small properties that do not have sufficient areas to establish crops.

b) Lack of capital and machinery to start agricultural activities.

c) Lack of experience in agriculture.

d) Time shortage or little desire to invest additional time to crops, and

e) Farm topography that does not permit crop establishment.

In summary, our survey indicates that the most immediate impact area for the arable layer building technology developed by CIAT is the Puerto López – Puerto Gaitán region, approximately 180 thousand hectares. It is considered that for its rapid adoption, investment by the Colombian government in improving road infrastructure is critical. In addition, in the more remote areas of the llanos there are a number of other critical factors (i.e. lack of machinery, inputs, technical assistance, qualified hand labor and roads and communications) that prevent the introduction of crops to establish rotations with pastures in sustainable agropastoral systems.

5.2 Development and validation of soil biological indicators of agro ecosystem health.

TSBFI-Africa

Completed Work

The role of indigenous knowledge in the management of soil fertility among smallholder farmers of Emuhaya division, Vihiga district. (MA thesis defended)

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The knowledge of local soils possessed by smallholder farmers was found to be elaborate. Knowledge of local soil was responsible for the naming, differentiation and classification of soils. The study also shows that farmers understand different processes that occur on their farms. They were, therefore, not only able to identify different landscapes but also recognize different niches.

Farmers also acknowledge that some of these niches, such as the home gardens, are as a result of human action while some, like valley bottoms and eroded surfaces, *esilangalangwe,* were a result of natural process. What is more, farmers understand that these natural processes can be facilitated by the action of farmers. The study has shown that farmers are familiar with the various soil types in their locations. This confirms the first assumption of the study that farmers have local diagnostic criteria for classifying soils. As discussed above, this study also confirms findings among farmers in other countries.

According to information obtained in this study, the local knowledge of soils is learnt through a number of sources, mainly experience and observation. The other sources mentioned include elderly farmers as well as parents. The role of scientist and researchers in the gathering and dissemination of this local knowledge of soils was also acknowledged. The implication here is that in addition to the farmers' indigenous knowledge, scientific knowledge is also needed for sustainable smallholder farming.

Because of the broad nature of their knowledge of local soils, farmers also have an indigenous criterion for diagnosing the soil nutrient status. It was observed that smallholders have a variety of ways which they employ to interpret the fertility status of the soils in their farms. Soil fertility, which is an invisible constituent of soil, is interpreted through soil characteristics such as colour, texture, depth and location. Farmers also diagnose soil nutrient status through plant and crop performances. This study also found that there are certain specific plant and animal species associated with different soil conditions. This seems to confirm the second assumption of the study that the situational status of soil fertility can be diagnosed through the observation of certain specific indicators. It was further learnt that the action taken by a farmer when the signs for soil nutrient depletion is witnessed depends largely on the type of the indicator. Diagnosing the situational status of the farm nutrient is, therefore, part of the wider repertoire of local agricultural knowledge.

Households within the study area were found to be engulfed in the crisis of poverty and this, coupled with the process of socio-cultural and economic change, was found to be a constraint to smallholders' efforts to manage the fertility of their croplands. The sizes of the family landholdings are gradually declining as the number of livestock owned by households also decline as a result of the social, demographic, cultural and economic transformations that are taking place in contemporary Kenya. These changes, to a greater extent, have profoundly altered the farming system and introduced landscapes that were unknown to the Abanyore. In general terms, smallholders' households were found to be undertaking certain strategies to support the management of their landscapes and croplands. However, it was also observed that smallholder farmers face a number of constraints in their effort to manage the fertility of soils. As reported here, indigenous soil management strategies that still survive have been overstretched and will require external support in terms of repacking if they are to be of any help to smallholders' needs. Largely because of these constraints and partly because of the nature of poor resource farmers, the responsive behaviour to soil nutrient depletion sometimes is not determined by the type of infertility indicator observed.

This study has revealed that farmers varied input use, crop choices and cultivation, depending on the niche type. For instance, no farmer reported the use of inorganic fertilizers in the home gardens. On the other hand, food production, income and labour, guided the farmers' management decision. The above argument partly confirms and partly disapproves the third assumption of the study that farmers' responsive behaviour to soil nutrient depletion depends on their cognitive view of soil fertility indicators. Data collected throughout the study reveal an existence of both indigenous and modern strategies of soil nutrient management within the study population that can be effectively manipulated to address the problems faced by smallholder farmers in the study area in managing the fertility of their soils. However, these strategies are not effectively dealing with the problem of soil nutrient depletion mainly due to the many changes identified above. Part of this inefficiency can be attributed to the varied number of constraints that farmers face in their effort to apply these strategies to their fields.

The soil fertility management practices adopted by farmers are mainly perceived as efforts meant to increase yield. Farmers prefer inputs that are relatively cheap, need considerably less labour to apply and benefit particular crops in the shortest time possible. Therefore, while farmers acknowledge that different soil types require different management strategies, some practices are crop specific or appear to be associated with a particular set of crops. However, farmers and the general community did not have an alternative strategy that could help smallholders improve crop productivity. In fact, key informants seemed to support the coping mechanisms widely used by farmers despite the fact that they were widely aware of the constraints faced by them in using these strategies. One can, therefore, not avoid concluding that crop productivity among smallholder farmers of Emuhaya seems to have no option but the enhanced management of the soils. Integration of farm nutrient management is the only sure way to enhance productivity on farmers' fields. This inevitably calls for the integration of knowledge systems (modern and indigenous).

Recommendations for Policy Makers and Implementers

- Policies designed to address the soil fertility management problems smallholders face should not look at farming in isolation. For such policies to be affective, and to be closely linked to the needs of smallholder farmers, they need to take into consideration the farmers' folk knowledge which incorporates both environmental and ecological aspects.
- Non-governmental organizations and research institutions working in the area should educate smallholders on the need to manage local soils appropriately. This should be done through helping the farmers to mobilize resources and start income-generating activities that would relieve poor families of the overwhelming constraints they face. In all initiatives designed to assist farmers, they should be made to take an active role, and their folk perspective in farming respected. This would facilitate acceptability and, may be, the long term sustainability of such initiatives.

On-going work

Scientific assessment of farmers' perceptions of soil quality indicators within smallholder farms in the central highlands of Kenya

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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 characterized 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. Special attention was given to agricultural weed species. Indicators for distinguishing productive and non-productive fields included crop yield and performance, soil colour and soil texture. A total of 18 weed species were used to distinguish between high and low soil categories. 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, 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.

This study was conducted on a sample population of 60 farmers in the 2003 long rain season, to determine their' perceptions of soil fertility and common soil management practices which influenced soil quality within farmers' fields in Chuka and Gachoka divisions, which fall in Meru South and Mbeere Districts respectively. Farmers were asked to identify soil fertility indicators that they used to determine fertility status of their soils in the productive or non-productive fields within their farms.

Farm selection for the study was done randomly in pre-selected sub–locations (Kirege and Gachoka sub–locations) in Chuka and Gachoka Divisions respectively. A list of villages was first obtained from divisional offices to constitute the sampling frame, from which the study farms were randomly selected. Social data was collected first from all farms (60), after which top soils were sampled from both productive and non-productive plots within smallholdings in both divisions. Soil sampling was then conducted on fifteen farms selected in both divisions from the farms that were visited in the household survey. In each village, two farms were then selected and sampled for topsoils (0-20cm). Soils were recovered by compositing, from a minimum of 10 randomly selected sites on farmers' fields. Lastly, half kilo (500g) subsamples were sealed and transported in cool boxes for laboratory analysis. In the laboratory, soils from the two divisions were were logged in and analysed separate batches (there were a total of two batches).

Soil chemical parameters that were determined included soil reaction (pH), exchangeable acidity, exchangeable bases (Ca and Mg), extractable phosphorus (Olsen), total organic carbon, available nitrogen, total nitrogen and total phosphorous, while physical parameters included soil texture and water aggregate stability. Routine methods outlined in the Tropical Soil Biology and Fertility manual were used to analyze soils. Throughout the chemical analyses, samples were randomly replicated within the batches for quality monitoring.

Results showed that farmers only used sensory information (soil tactile and visible characteristics) to distinguish within soil fertility categories. The most important indicators for characterising productive and non-productive fields included crop yield (86%) and performance (76%), soil colour (60%) and soil texture (40%) in Chuka division while in Gachoka, soil colour was the most important indicator (84%). A total of 18 indicator plant species were used to distinguish soil fertility status in both divisions.

There were significant statistical differences among soil fertility categories, using parametric techniques (ANOVA) for key soil properties ($p < 0.05$), implying that the soils must have belonged to different populations and that there was a qualitative difference in the soils that were chacterised as different by farmers. In both sites, fertile soils had significantly higher pH ($p<0.001$), total organic carbon and exchangeable calcium ($p<0.001$), and magnesium ($p< 0.05$). Available-N was also significantly higher in fields rated as fertile in Gachoka division, but not within fields in Chuka division (Table 54).

Table 54: Soil chemical properties from high and low fertility sites in Chuka and Gachoka divisions.

Soil Quality Category	Total N	Total P	C	N	P	Ca	Mg	PH
	%			mgkg^{-1}			cmol$_c$ kg^{-1}	
Chuka								
High	0.16a	0.05a	33.6a	2.74a	20.5a	8.2a	3.1a	5.6a
Low	0.16a	0.05a	24.3b	2.79a	16.0a	7.5a	2.8b	5.1b
SED	0.02	0.01	3.99	0.16	4.27	0.65	0.12	0.08
Gachoka								
High	0.16a	0.05a	15.2a	2.43a	17.8a	5.8a	1.8a	6.5a
Low	0.02a	0.05a	12.5b	1.40b	6.2a	3.8b	1.3b	6.4b
SED	0.18	0.01	0.18	0.21	7.27	0.48	0.15	0.09

The productive soils showed a higher pH ($p<0.001$) and exchangeable cations than non-productive soils in both divisions. Exchangeable cations also varied significantly for Mg ($p<0.05$) in both divisions, while Ca ($p<0.001$) was only significantly different within sites in Gachoka division. Comparing pH and exchangeable bases between sites, it was observed that overall, they were higher in Gachoka, which due to less rainfall, is semi-arid as compared to humid conditions in Chuka division.

In conclusion, 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.

TSBFI-Latin America

Completed work

Evaluating soil quality in tropical agroecosystems of Colombia using NIRS

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In order to evaluate the impact of agricultural development models on the quality and health of the soil, it is necessary to monitor the physical, chemical and biological quality of the soil precisely, using sensitive and efficient techniques that make it possible to detect significant changes in the condition of the same. Near Infrared Reflectance Spectroscopy (NIRS) analysis makes it possible to evaluate soil characteristics related to organic matter (OM) including carbon, nitrogen, phosphorus, moisture content, cation exchange capacity, clay content and $CaCO_3$, among others. This technique has been widely used for several decades to determine the moisture content in seeds, determination of dry matter and crude proteincontents, the state of decomposition of dead leaves, C, N and P contents in plant material, sugar content in fruits and to identify or characterize polymers, pharmaceutical, petrochemical and other industry products. While it has been shown that it is possible to measure moisture, OM and total N contents simultaneously, using NIRS. The prediction is relatively poor, however, when the concentrations of C and total N are relatively low (C <0.3% and N <0.03%) and in soils with a broad range of colours. In addition, studies in Australia have shown that the cation exchange capacity, the exchangeable Ca and Mg, the Ca:Mg ratio, organic C, and percent exchangeable sodium and aluminium were adequately predicted by NIRS at specific agricultural sites. Shepherd and Walsh (2002) developed a scheme that makes it possible to use a library of spectra of soils from eastern and southern Africa to estimate, quickly and non-destructively, certain soil properties such as Ca, Mg, K and exchangeable P, organic C, pH, potential mineralization of N, effective cation exchange capacity, and particle size and distribution, based on diffuse reflectance spectroscopy analysis.

The application of NIRS in soil analyses has generally focused on the prediction of some of its properties through calibration and validation, and the main interest on simplifying this analysis vis-à-vis the traditional chemical methods. Nevertheless, the potential of NIRS as a technique capable of separating soils submitted to different agricultural uses and diagnosing its quality has not been exploited. The purpose of this work was to assess the capacity of the NIRS for evaluating soil quality, as reflected in its OM contents and composition, and in some chemical and biological properties.

Near infrared reflectance spectroscopy (NIRS) analysis was used to distinguish among soils of different agroecosystems in Colombia, based on differences in quality and quantity of organic matter and in certain chemical and biological properties (Table 55).

Table 55. NIRS wavelength values (nm) characteristic of the soil-use systems.

Wavelengths (nm)	Soil-Use System*
400-560	CP
580-740; 1220-1420	ERO, DPG
760-1200; 1900-2220	FWL, CPS
1440-1880; 2240-2400	SF, PAS, CPS

* CP = coffee plantation, CPS = coffee plantation under shade, DPG = degraded pasture with grazing, FWL = fallow in water-logged zone, PAS = ungrazed pasture, ERO = soil-eroded plot without vegetation. FAC = 1-year fallow after intensive cassava crop, SF = secondary forest

A correlation was sought between the wavelengths determined by NIRS and certain chemical properties of the soil (Ca, Mg, K, Al, total P, N-NO^-_3, P-Bray II, N-NH^+_4), the percentage of carbon content in different fractions separated by size and density (LUDOX), and microbial activity measured by respirometry in the laboratory.

The variables evaluated were 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 organic matter fractionation) and (iii) NIRS variables (101 variables given by the absorptions in the near infrared region). For each group of variables, a principal component análisis

(PCA), together with discriminant analysis, was run. Each group of variables separated the different soil-use systems (***P <0.001) similarly. Afterwards, 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 (Table 56).

Table 56. Results of the multivariate analyses run using NIRS data, chemical, OM related variables.

	PCA[b]		**Discriminant Analysis**		**Analysis of Co-Inertia**			**Statistical Significance[c]**
Variables	**Factor (%)**		**Factor (%)**		**Variables**	**Factor (%)**		
	1	2	1	2		1	2	
NIRS 240	38.5	30.8	48.15	33.5				
NIRS 50	45.82	31.58	56.38	31	NIRS/OM	67.49	23.67	P <0.001
Chemical	47.25	27.67	59.26	24.67	NIRS/Chemical	65.55	30.74	P <0.001
OM[a]	38.66	23.86	48.13	23.86	Chemical/OM	86.21	8.14	P <0.001

[a]OM= Organic matter
[b]PCA+ Principal Component Analysis
[c]Statistical significance same for all multivariate analyses

These results show 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.

5.3 Develop working approaches towards collective action to arrest land degradation (e.g. gully stabilization)

5.4 Development of cross-scale practices for management of soil biota-mediated agro ecosystem services.

5.5 Trade-offs/win-win situations between agricultural productivity and ecosystem service provision evaluated.

TSBFI-Africa

On-going Work

Relationships between organic resource quality and the quantity/quality of the soil organic matter pool

H Wangechi and B Vanlauwe

See report on activity 1.1.

TSBFI-Latin America

On-going work

Payment for environmental services in the Fuquene watershed (Colombia): Physical parameters, carbon stocks and fluxes of greenhouse gases

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The Water and food challenge program approved to CONDESAN a project to pursue the "Payment from environmental services as a mechanism to promote rural development in the upper watersheds of the tropics". Environmental services considered include the provision of water, biodiversity conservation, prevention of soil erosion and potential for mitigation of net emission of greenhouse gases (GHG) and carbon sequestration. The project will operate in a group of nine pilot watersheds in various Andean countries. The Fuquene Watershed in the central part of Colombia, near Bogotá, was selected to initiate the project and to test methodologies that later will be used in the assessment of the other watersheds. The Fuquene lagoon collects the water from the watershed and provides water to a vast number of villages and agricultural fields in neighboring areas. Despite numerous governmental, bilateral and private projects that have operated in the watershed, the lagoon, suffers an accelerated rate of reduction in area/water volume as well as eutrophication, due to several factors including border land recovery by ranchers, pollution of incoming water with sewage sludge, animal manure and nutrients leached from fertilizers etc. The watershed covers an area of 187,000 ha. Main production activity in the watershed is intensive cattle raising. The most productive dairy farms in Colombia are likely located in this region. Total area covered by pastures (mainly Kikuyo grass in the lower basin and Ryegrass in the medium to upper part) is 110000 ha (59% of the area). Potato is the main crop in the watershed and is usually managed with conventional tillage, which involves major soil disturbance which promotes soil erosion and nutrient leaching. Total area under crops is around 48000 ha (26% of the area). In recent years as a result of activities from a GTZ project, no tillage systems have been promoted and are slowly gaining acceptance by potato growers. There are some 2000 ha of no till potato now in the watershed.

Our contribution to this project will make a quantification of the status of the most important soil physical characteristics that regulate soil function in relation to water, nutrient storage and leaching. We will also assess total carbon stocks in soils and biomass as well as net fluxes of carbon dioxide, methane and nitrous oxide in the watershed and also will quantify C stocks and GHG for the dominant land use systems. The purpose is to identify the land use systems that are more beneficial or detrimental to the environment. This information will be contrasted with information on sustainability of land use and the socioeconomic of main production systems collected by other researchers as part of the project. Win- win systems could then be promoted to help policy makers and local authorities to reorder land use in the watershed to maximize benefits for local farmers and communities as well as for neighboring receivers of water and services and for the global environment.

Seven dominant land use systems on similar soils (hydrologic response units-HRU) were selected to fall within four transects: one longitudinal transect crossing the watershed from south to north and three perpendicular transects distributed along the main axes to spread along the watershed. Selected HRU included: Paramo native vegetation, mountain secondary forest, potato crops under conventional and no tillage, Ryegrass pastures, Kikuyo intensively managed pastures, and degraded land that not longer supports productive uses. These HRU were replicated three times trying to cover the spatial variability found in the watershed. A total of 21 sampling plots were selected.

Soil C stocks: In each of the 21 plots, three soil pitches ($0.5 \times 0.5 \times 1$m) were open: Pitches were located at three altitudinal position within each plot. Upper part, medium and lower part of the plots. In each pitch, composite soil samples were collected at four depths (0-5, 5-20, 20-40, and 40-100) to measure bulk density and determine total Carbon stocks in soils. Soil samples will be analyzed using conventional wet oxidation methods to assess oxidable carbon and by CHN analyzers to measure total carbon. In areas where the history of land conversion from C3 type dominated vegetation (i.e native forest) to C4 dominated species (some grasses, maize, sorghum etc), or from C4 into C3 vegetation, is well known and reliable, ^{13}C determinations will be made in soil samples to assess the rate of replacement of new organic matter and to establish C partitioning between soil pools of different mean residence times.

Soil Physical parameters: At the time of soil sampling some soil physical characteristics were evaluated in situ: resistance to penetration in the soil profile using a penetrograph and soil shear strength (torcometer). Samples were collected for bulk and particle density determinations measuring saturated hydraulic conductivity, air permeability, resistance to compaction, and water retention characteristics. As physical condition define how water can be store and move into the soil profile, a good understanding of the behavior of the physical soil profile in relation to water fluxes will allow to define if there are possibilities of contamination with elements coming from fertilizers or not. As also they define, the hydrologic response of the soil in relation to rainfall, they will allow to understand the relationship between rainfall and rainfall acceptance capacity of the soils, runoff production as well as the vulnerability of soils to be eroded. This knowledge will help to track sources of contamination of the lagoon and the loss of the water mirror and will be used to define solutions to control degradation problems.

Carbon in plant biomass will be done through allometric equations for trees and shrubs and by harvesting representative subplots of crops and pastures. Allometric equations will be developed for selected species when not available.

Greenhouse gases: Fluxes of carbon dioxide, methane and nitrous oxide, the three most important GHG related to land use change and agricultural activities, are being monitored on an annual basis to follow at least a full cycle of climatic variations. One of the replications for the seven HRU was selected for monitoring gases. In each plot four replicate sampling points were selected and georeferenced. A PVC collar (30 cm diameter, 10 cm height) was permanently installed in the soil to a depth of 8 cm. A closed vented chamber is attached to the collar at the time of gas collection. Four gas samples are collected per chamber at times 0, 10, 20 and 30 minutes. Chamber temperature is measured at every sampling time. A biweekly sampling frequency is used. Gas samples are stored in pre-evacuated glass vials and are analyzed within two weeks after collection by gas chromatography (ECD and FID detectors) for CH_4, CO_2 and N_2O. Gravimetric soil water content is measured at every sampling time. Soil redox potential, pH and soil temperature is measured in situ and soil samples are collected periodically for monitoring ammonium and nitrate levels.

Integration of annual fluxes of both C and GHG will be done at the watershed level by using similar hydrologic response units and adding them using land cover data from remote sensing and GIS techniques. Once annual data is collected and the global warming potential of different HUR is calculated, a modeling process could be conducted to estimate how the reordering of land use systems in the watershed will influence the interaction with the environment.

Figure 40 shows partial data on soil shear strength for the dominant land uses found in the watershed. Data for one of the replicates is showed. The paramo sites show values of shear strength above the threshold value (60 kPa) considered as acceptable for plant growth. This is an indication of surface soil hardness even under natural condition and explain why farmers have to use tillage to overcome this limitation. No tillage systems clearly reduce surface soil strength favoring the developing of the root systems. Intensively managed pastures have resulted in very high surface strength, likely as a result of cattle trampling. Degraded soils showed the most extreme levels of soil compaction. This will surely, root establishment preventing any productive use of the soil under current conditions. Land rehabilitation strategies should be implemented to reduce these limitations to tolerable levels that allow plant growth. Soils under no tillage crops exhibit an adequate physical environment for root development.

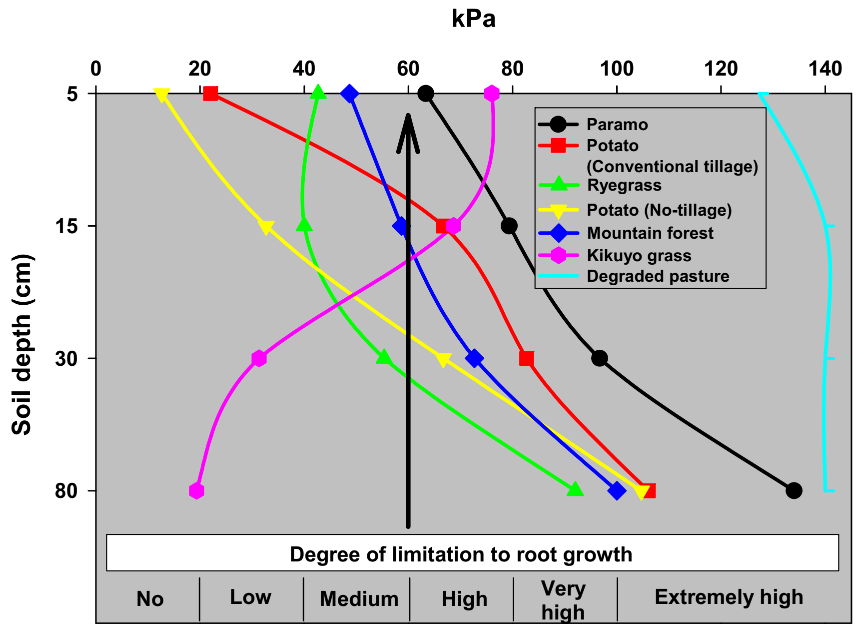

Figure 40. Soil shear strength for diverse land use systems on the upper Fuquene watershed (Colombia)

5.6 Integration of plot-farm-watershed and higher-level information related to the target ecosystem services across scales.

5.7 Local and formal monitoring systems to evaluate the impacts of ISFM options and other land management practices on ecosystem services developed.

5.8 Develop or identify systems that contribute to C sequestration and mitigate greenhouse gas emission

Completed Work

Carbon Sequestration Potential of the Savannas (Llanos) of Colombia and Venezuela

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Neotropical savannas of Latin America represent one of the last frontiers where agriculture could be expanded in the world. These savannas are located in Brazil (204 Mha), Venezuela (25 Mha), Colombia (23 Mha), Bolivia (13 Mha) and Guyana (4 Mha). Savannas in Colombia and Venezuela are called Llanos (flatlands) and constitute a continuous and relatively homogeneous system of nearly 50 Mha. Soils in the Llanos are dominated by very acid oxisols, low in natural fertility and high in aluminum saturation, which prevent good performance of non adapted species. Soil are considered fragile and very susceptible to degradation. Intensive tillage operations have resulted in serious loss of physical stability. In the last three decades, government programs have promoted the expansion of agriculture and livestock in the

Llanos, particularly in Venezuela. Expansion of pastures in Latinamerica was triggered by the introduction and improvement of grasses coming from Africa, particularly *Brachiaria* species. Pioneering studies at CIAT done in the Colombian Savannas showed that these deep rooted grasses are able to increase soil organic content in the soil at rates ranging from 1 to 3 Mg $C.ha^{-1}y$-1. Our own subsequent studies found that conversion of tropical savannas into pastures or even cropland with appropriate management could result in a net decrease in net fluxes of various greenhouse gases from the land into the atmosphere and could generate net carbon equivalent gains. Tropical agroecosystems have an intrinsically high net primary productivity and are consequently of interest by their high potential to sequester atmospheric carbon , that could be traded trough the CDM or similar mechanisms to compensate emissions reductions that developed countries are unable to fulfill internally. We made an attempt to estimate the total carbon storage in soils from the Llanos under current land use system and to estimate the maximum potential of the region to capture atmospheric carbon in soils and finally to make an estimate of the range of feasible carbon accumulation that could be expected in the region in the coming two decades given the development plans foreseen for the region.

We made a comprehensive literature review of available information in both Colombia and Venezuela, relative to soil carbon levels and stock in different subregions, natural land cover, crops, cropping systems, forest plantations etc. The Llanos were grouped in a set of various subunits corresponding to the dominant landscape positions having relatively homogeneous soil conditions. Recent land cover was generated for this study using satellite images. For Colombian Llanos, a recent soil survey from the National geographic institute including more than 500 sampling sites across the Llanos which include data on soil carbon as well as bulk density was used to estimate carbon stocks. In Table 57, Carbon stocks in soil (0-30 cm depth) are presented for the main landscape positions and land cover found in the Llanos of the two countries.

Despite recent land intensification, the Llanos are still dominated by native vegetation. Land use conversion has been much more accelerated in Venezuela than in Colombia as a result of more infrastructure and development programs at the National level. Carbon content in the soils is not homogeneous among the main landscape positions. There is a west – east gradient of soil carbon with the higher values near the Piedmont from the Andes in the west and the lower values towards the Orinoco floodplain in the east. Similarly gradients in soil bulk density do exist and sand seems to increase from west to east. This is likely the result of millennial continuous movement of sediments and eroded materials from the Andes to the east. There is also a clear gradient in precipitation with the higher annual values (2700mm) in the Andean piedmont to 800 mm in the Orinoco Delta.

Our estimate for total carbon stored in the top 30 cm of soils from the Llanos results in a value of 3.1 Pg C. Different land uses result in different C stocks. Estimated values should be viewed with some caution given the various assumptions in terms of homogeneity of functional subunits and carbon content in soils that we were forced to make to compensate the lack of more precise data.

In this study, the results of a long term experiment in the middle of Colombian llanos (Carimagua research station) confirmed previous findings that the conversion of native savanna vegetation to improved pastures (*Brachiaria humidicola* associated with forage legumes) resulted in net C accumulation in the soil of around 2.5 $MgC.ha^{-1}.y^{-1}$ over an 8 years period. A theoretical conversion of all available land into improved pastures, could potentially result in a net C accrual in soils of about 1.02 Pg of C. Savannas are however unique ecosystems that are host to a high diversity of endemic species of fauna and flora and play important though still poorly known roles in the regional biogeochemical cycles. Therefore it is necessary to balance the Government plans to develop the region with the necessity to preserve adequately sized areas under natural conditions.

Examination of national plans of Colombia and Venezuela to intensify agriculture and livestock in the Llanos in the coming 20 years and analysis of historic trends in land use change suggest that around 5 M ha of new pastures will be added as well as 1 M ha of crops and 1M ha of forest plantations. With these projections, we estimate that approximately 160 TgC can be added to soil C stocks in the next 20 years in the Llanos. Trading of these carbon C capture could potentially result in appreciable resources flowing to the region. However, a great deal of effort is necessary at various levels before this potential could be materialized.

Table 57. Estimated carbon stocks for the main land use systems in the Llanos from Colombia and Venezuela.

Ecoregion	Area (Mha)		Estimated Soil Carbon stocks (0-30 cm depth)			
			Colombia	Venezuela	Colombia	Venezuela
	Colombia	Venezuela	$MgC.ha^{-1}$		Tg C per Land cover	
Remaining Natural systems						
Elevated plateaus	7.29	5.04	73.98	35.66	539.3	179.8
Well drained lowlands	2.51	4.81	83.54	43.16	209.7	207.6
Poorly drained low plains	2.13	5.45	89.92	59.41	191.5	323.8
Rolling hills	6.84	1.66	48.07	40.00	328.8	66.4
Gallery and deciduous forest	2.65	1.52	138.60	75.00	367.3	114.0
Subtotal	*21.42*	*18.48*			*1636.6*	*891.6*
Modified systems						
Introduced pastures	0.98	5.00	98.20	78.00	96.2	390.0
Annual crops-conventional tillage	0.39	0.83	70.49	38.10	27.5	31.6
Annual crops-reduced tillage	0.001	0.17	72.90	43.20	0.07	7.34
Tree plantations	0. 1	0.80	73.39	27.00	7.34	21.6
Urban, water bodies	0.72	0.90			-	-
Subtotal	*2.19*	*7.70*			*131.1*	*450.6*
Total per country					1767.7	1342.2
Total for the Llanos					**3110**	

On-going Work

The TSBFI-LA team will continue its collaboration with the C-sequestration project, supported by the Netherlands Cooperation (Activity CO-010402): "Research network for the evaluation of carbon sequestration capacity of pastures, agro-pastoral and silvo-pastoral systems in the American Tropical forest ecosystem". Its main goal is to contribute to sustainable development, poverty alleviation and mitigation of the undesirable effects of greenhouse gasses on climate change, in particular CO_2. It combines efforts from the National Research Community, represented by CIPAV and Universidad de la Amazonia and the International Research community represented by CIAT, CATIE and Wageningen University and research center.

Under this project two major activities have been done: (i) a chapter for a book edited by R. Lal on potential of C-sequestration in the Andean hillsides, and (ii) an article for Agroforestry Journal on the overview of the project.

5.9 Crop, pasture, fallow, water, and soil management strategies developed to minimize sources and/or increase sinks of GHGs