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

TSBFI-Africa

- 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.

TSBFI-Latin America

- 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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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

A.O. Esilaba, P. Nyende, G. Nalukenge, J.B. Byalebeka, R.J. Delve and H. Ssali.

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, 34⁰ 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.

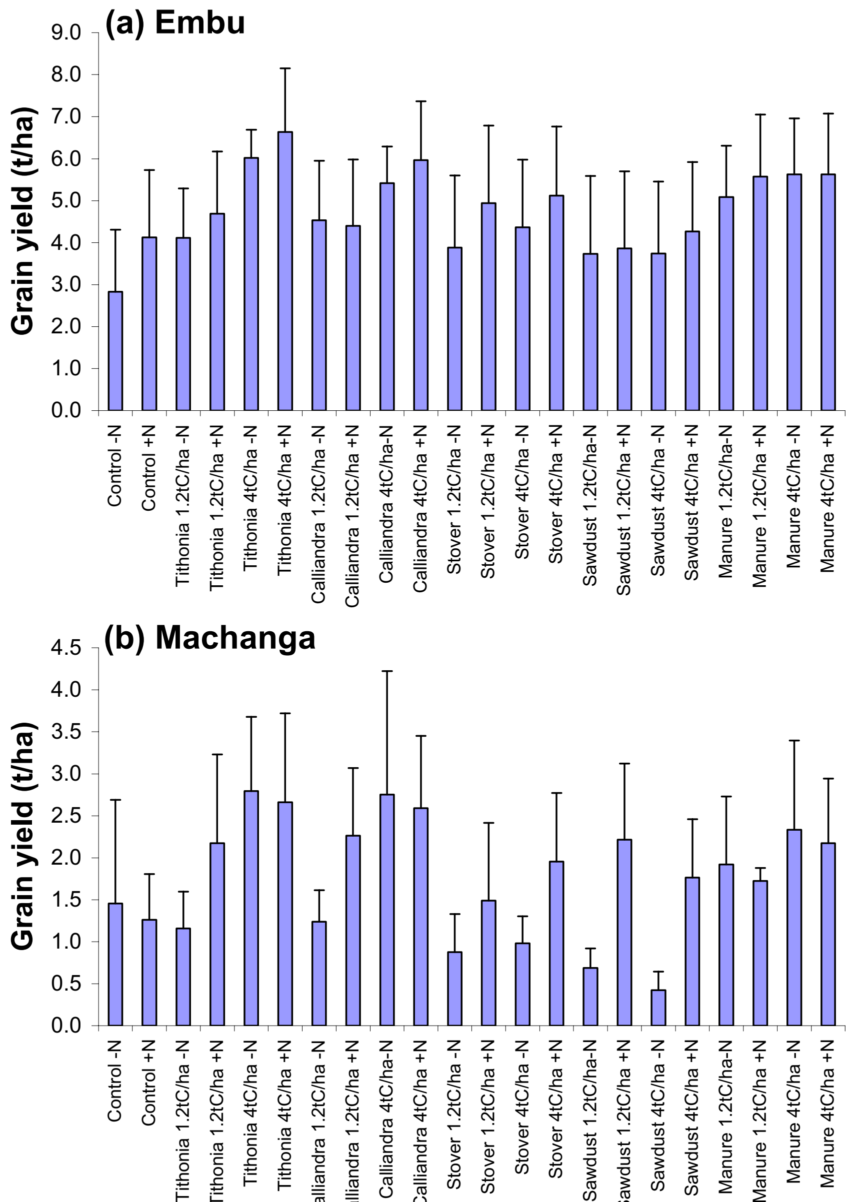


Figure 2. Maize grain yield as affected by application of organic resources of varying resource quality and/or mineral N fertilizer. Data presented are average values over 5 cropping seasons. Error bars are standard deviations.

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.

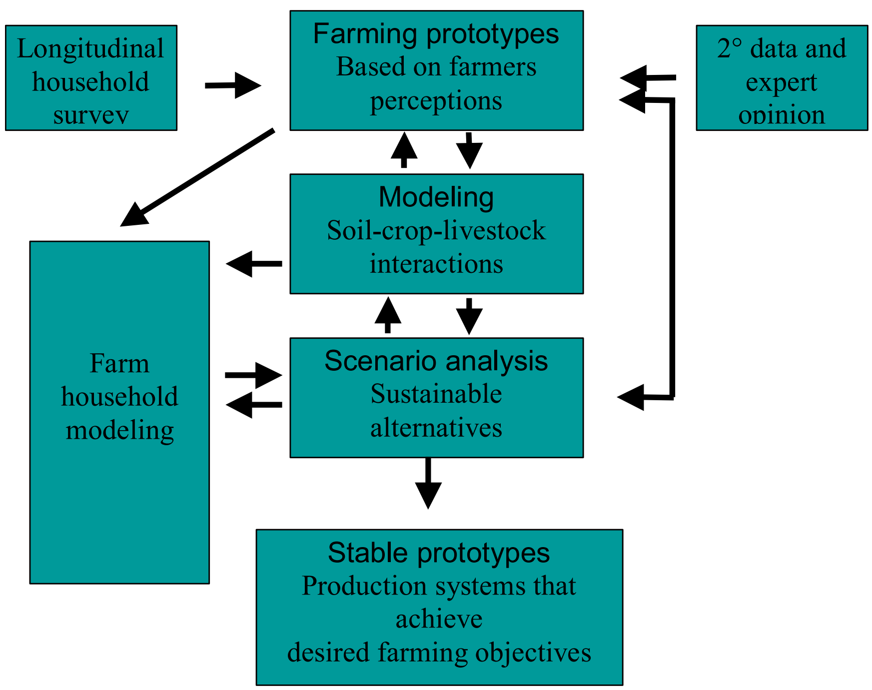


Figure 3. System prototyping and impact assessment for sustainable alternatives in mixed farming systems in high potential areas of East Africa (Ref: M. Waithaka, P. Thornton, H. Booltink, K. Shepherd, R. Kaitho, W. Thorpe and B. Salasya, 2002).

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.

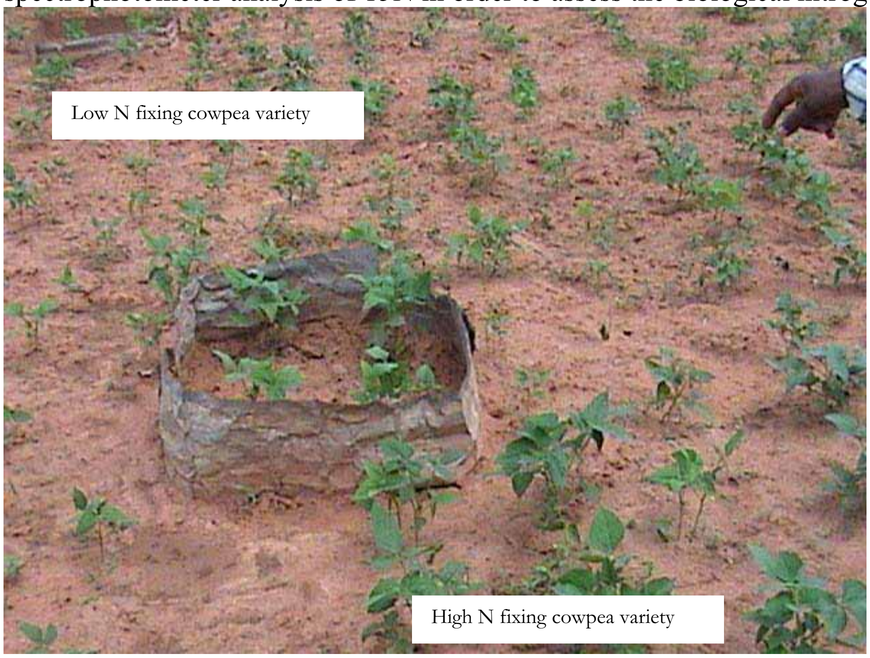


Photo 1: Cowpea varieties in N fixation trial at Gaya, Niger. Different cowpea varieties have different capability in N fixation.

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.

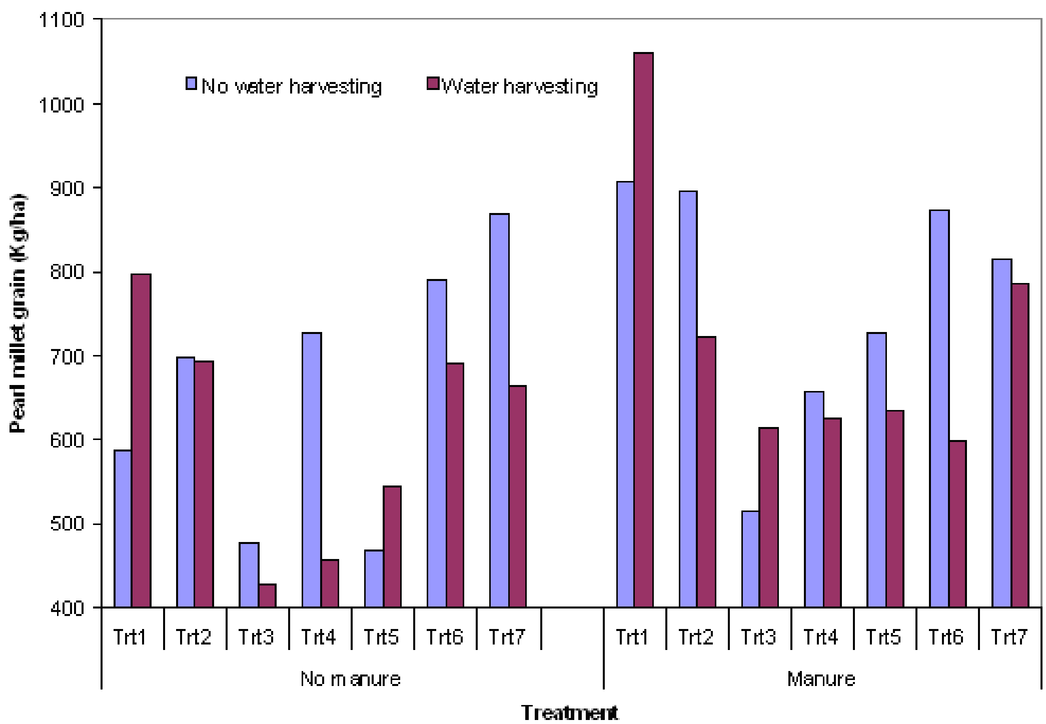


Figure 4: Pearl millet grain production as influenced by water harvesting, manure and mineral fertilizer application at SIRIBOUGOU, Mali in 2003.

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.

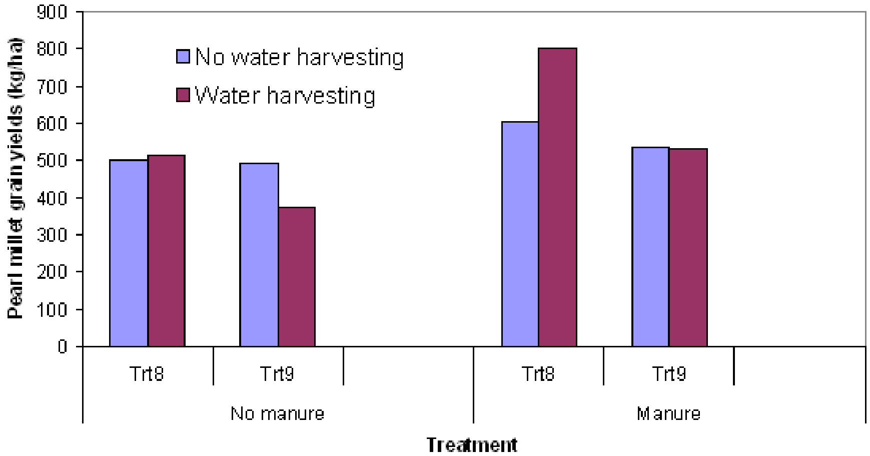


Figure 5: Pearl millet grain production in an intercrop with common beans as influenced by water harvesting, manure and mineral fertilizer applications at SIRIBOUGOU, Mali in 2003.

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.

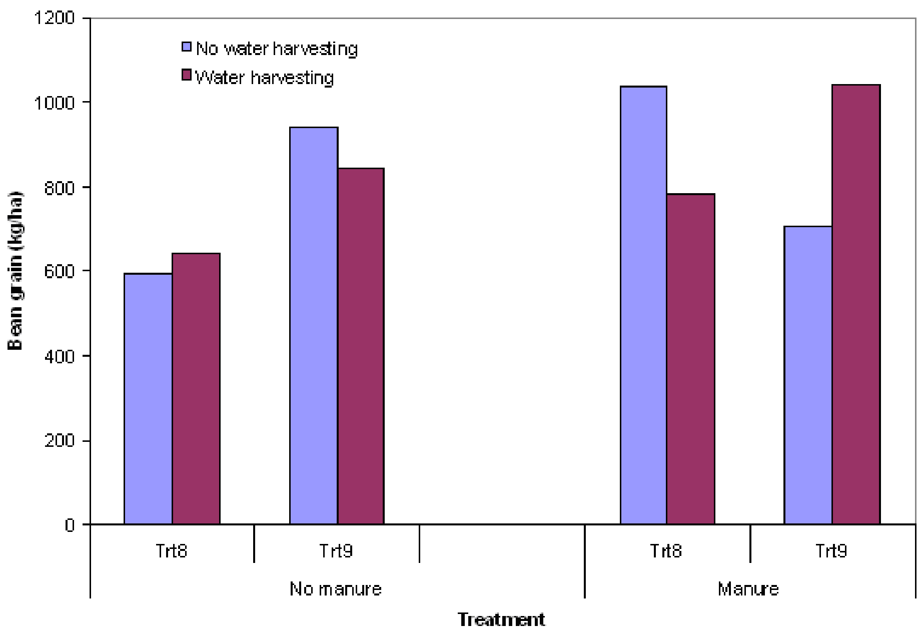


Figure 6: Bean grain production in an intercrop with pearl millet as influenced by water harvesting, manure and mineral fertilizer applications at SIRIBOUGOU, Mali in 2003.

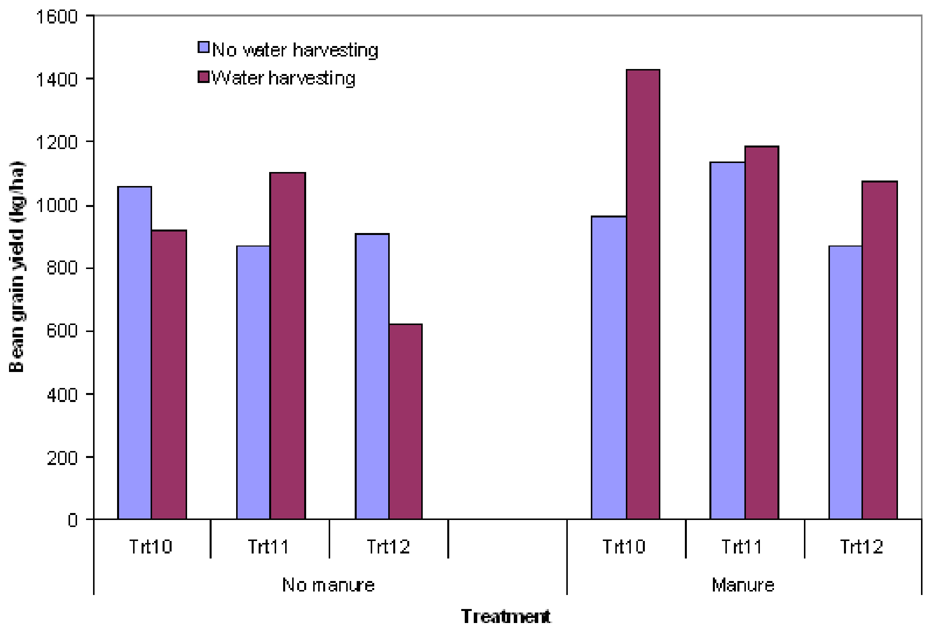


Figure 7: Bean grain production as influenced by water harvesting, manure and mineral fertilizer applications at SIRIBOUGOU, Mali in 2003.

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.

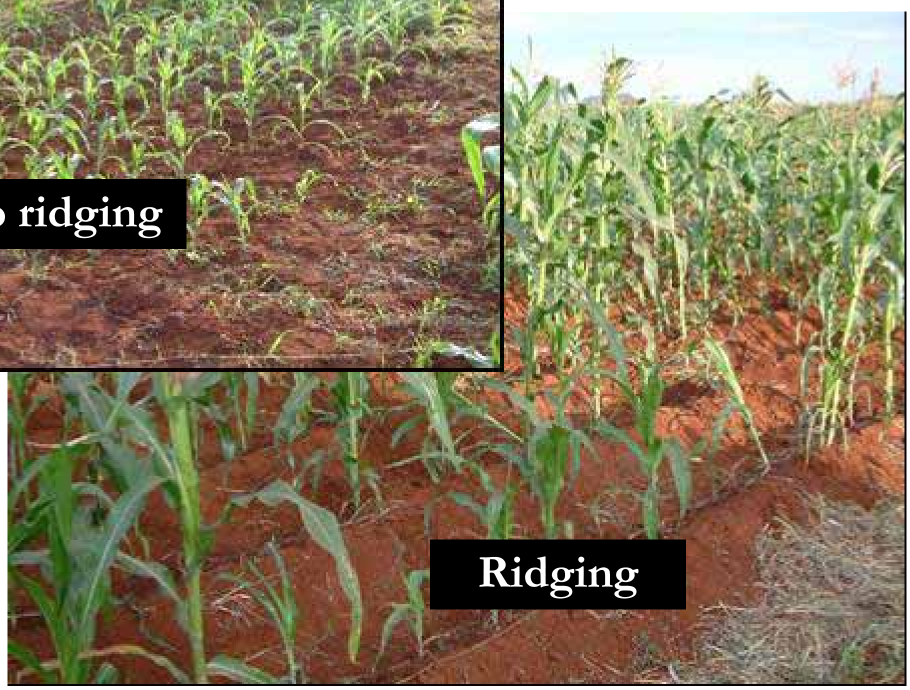
Goat manure at a rate of 5tha^{-1} was applied in the planting holes. Fertilizer was applied at 0 and 40 kg P ha^{-1} in treatments having P; and 0, 40, 80 and 120 kg N ha^{-1} for plots receiving nitrogen. Tripple superphosphate (TSP) and Calcium ammonium nitrates (CAN) fertilizers were used as source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

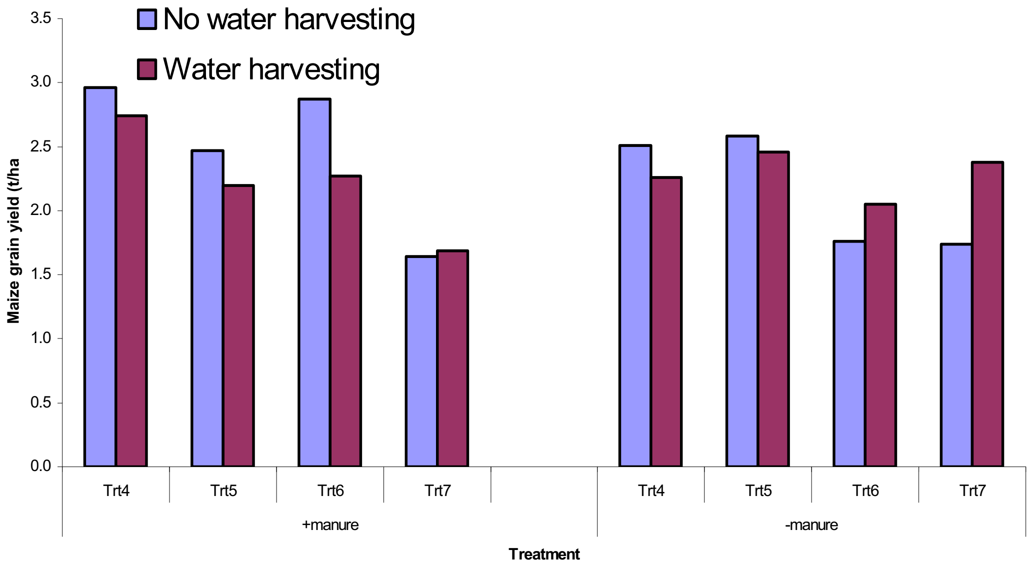


Figure 8. Effect of water harvesting, manure and mineral fertilizer application on maize grain yield at Kiboko, Kenya 2003 rainy season.

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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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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Acta Agronómica 52(1-4): 29-37(2004)

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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***Journal of Sustainable Agriculture* 23 (4): 39-50 (2004)**
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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In: R. J. Delve and M. E. Probert (eds) Modelling nutrient management in tropical cropping systems. ACIAR Proceedings No. 114: 126-134. Australian Center for International Agricultural Research (ACIAR), Canberra, Australia.
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).

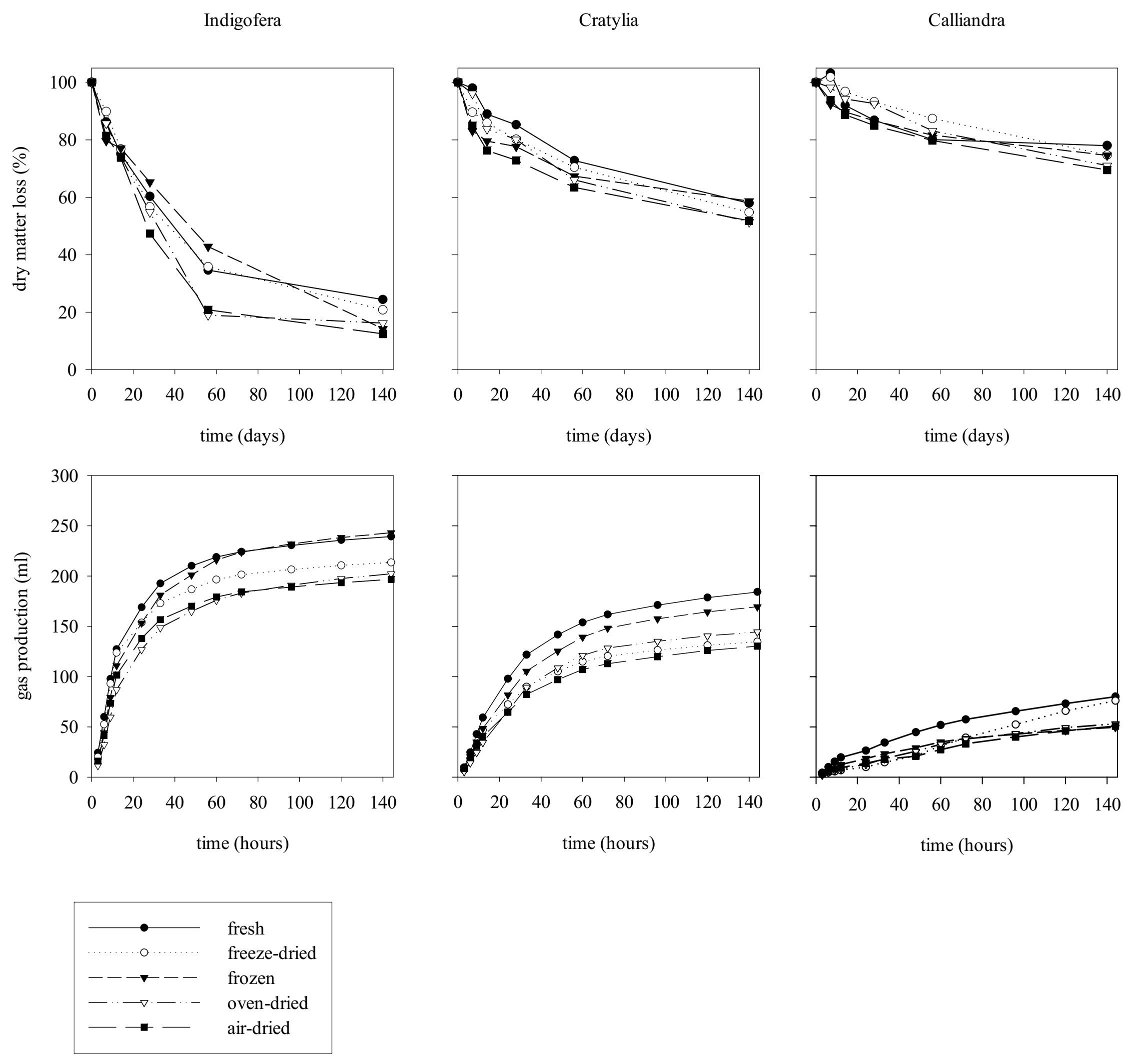

Figure 9. a) Percentage of initial dry weight remaining of Indigofera, Cratylia and Calliandra residues as affected by 5 different post harvest treatments during 140 days (aerobic methods) of decomposition in a greenhouse litterbag experiment, b) extent of gas production (ml) of Indigofera, Cratylia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

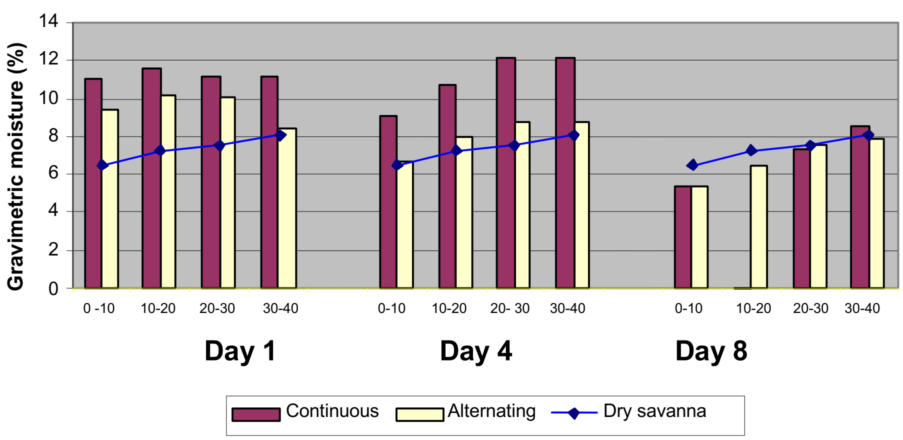

Figure 10. Percent gravimetric moisture by soil depth in a light-textured soil, 1, 4 and 8 days after applying five rates of water (20 L each) continuously or on alternating days.

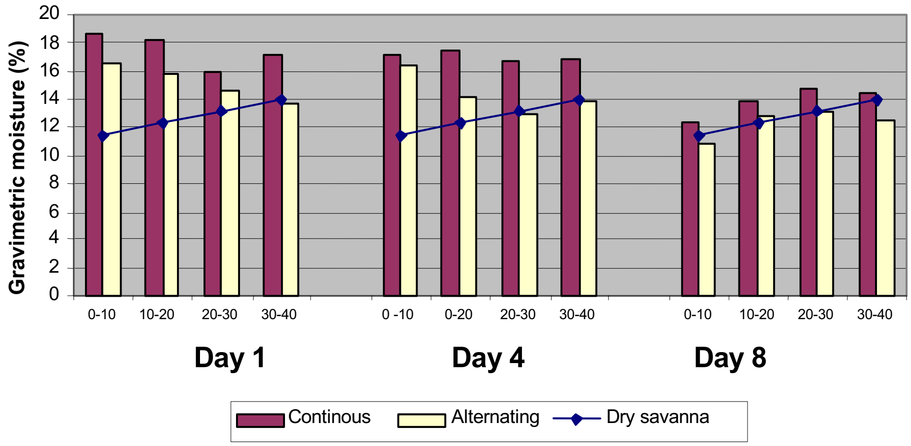

Figure 11. Gravimetric moisture content (%) in a heavy-textured soil, by depth, 1, 4 and 8 days after applying 5 rates of water (20 L each) continuously or on alternating days.

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

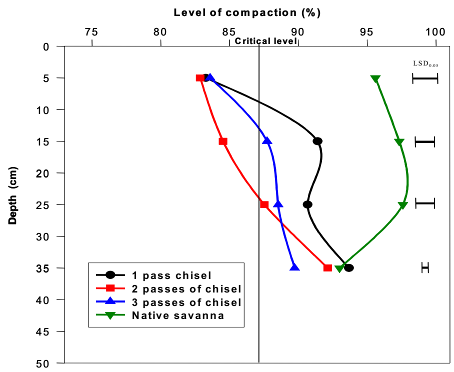

Figure 12. Compaction levels in the rice/soybean rotation at different soil depths in relation to the tillage and the critical level.

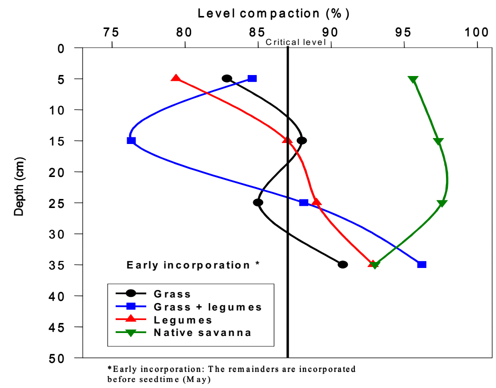

Figure 13. Compaction levels at different soil depths in the early incorporation treatments in relation to the critical level.

$Mg.m^{-3}$, 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 $p \leq 0.05$ 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 $p \leq 0.05$ 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.

		2000			
No	**Treatment**	**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.

		2001			
No	**Treatment**	**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.

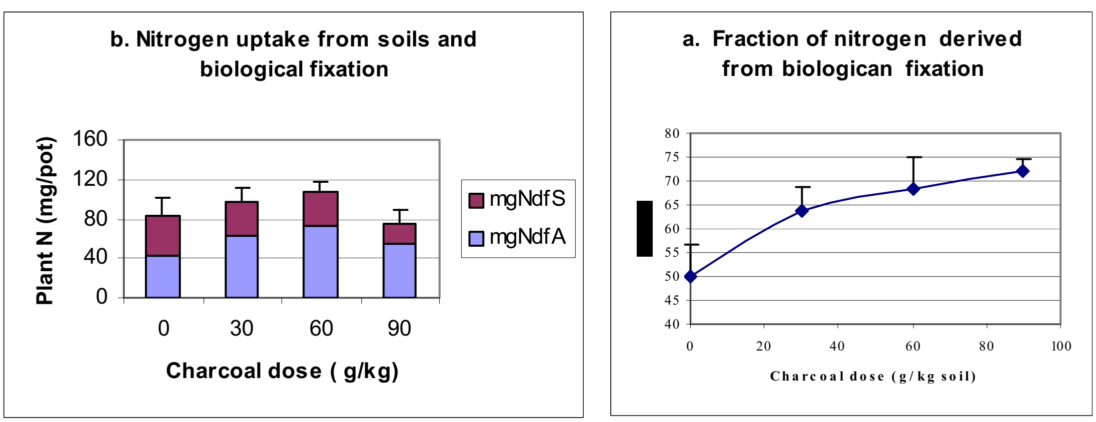

Figure 14. (a) Effect of increasing doses of charcoal addition on the proportion of nitrogen derived from BNF (%NdfA) and (b) plant nitrogen derived from soil (NdfS) and from biological fixation (NdfA) by plants of common beans.

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).

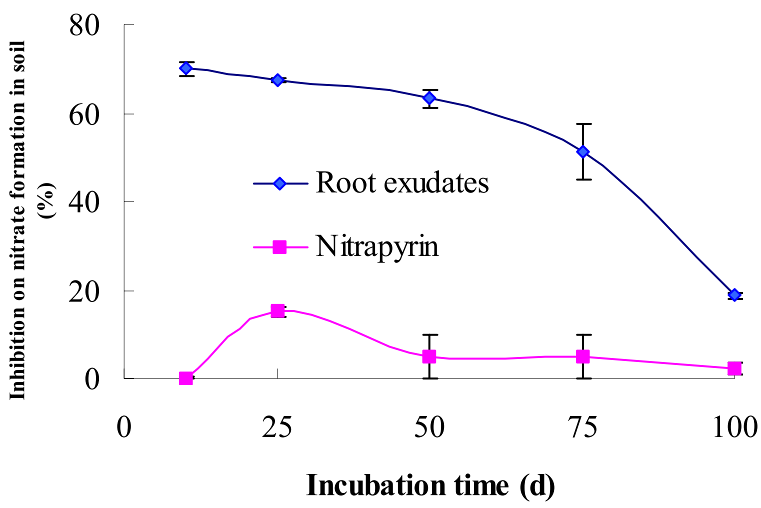

Figure 15. Inhibitory effect from root exudates (10 AT units NI activity g^{-1} soil) and nitrapyrin (4.5 ppm) on nitrate formation in soil during 100 d incubation period (Note: In control, nearly 90% of the added NH_4-N was nitrified by 75 days).

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).

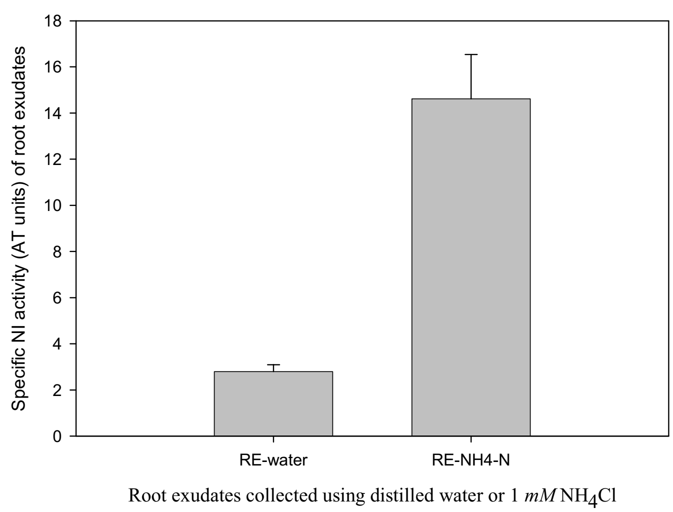

Figure 16. Influence of NH_4-N in the root exudates collection medium on the release of NI activity into root exudates from *B. humidicola* roots (Specific NI activity = NI activity g^{-1} root dry weight).

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*.

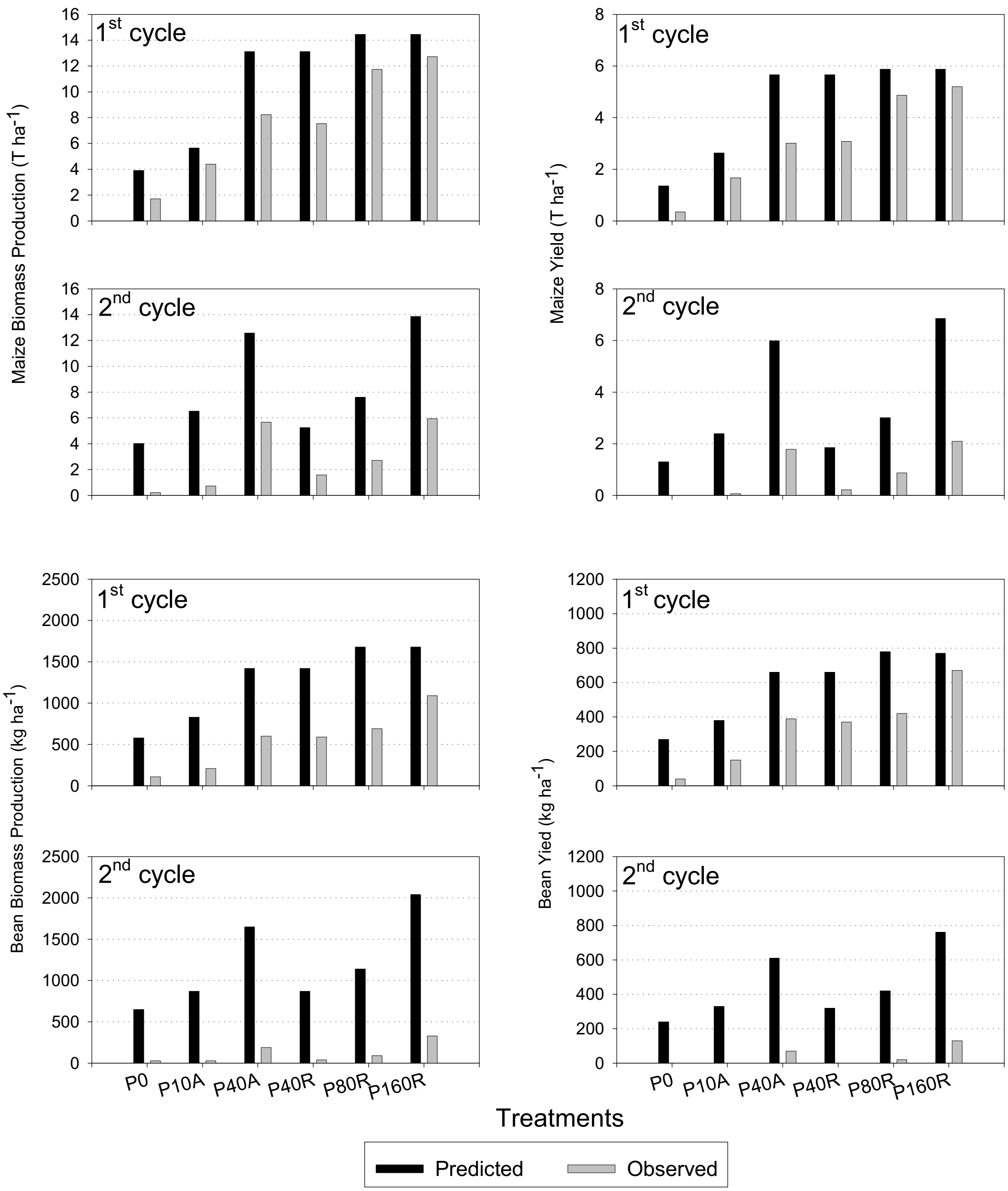

Figure 17. Predicted and observed yields of shoot biomass and grainfor maize/bean rotation with different applications of triple superphosphate in Pescador, Colombia.

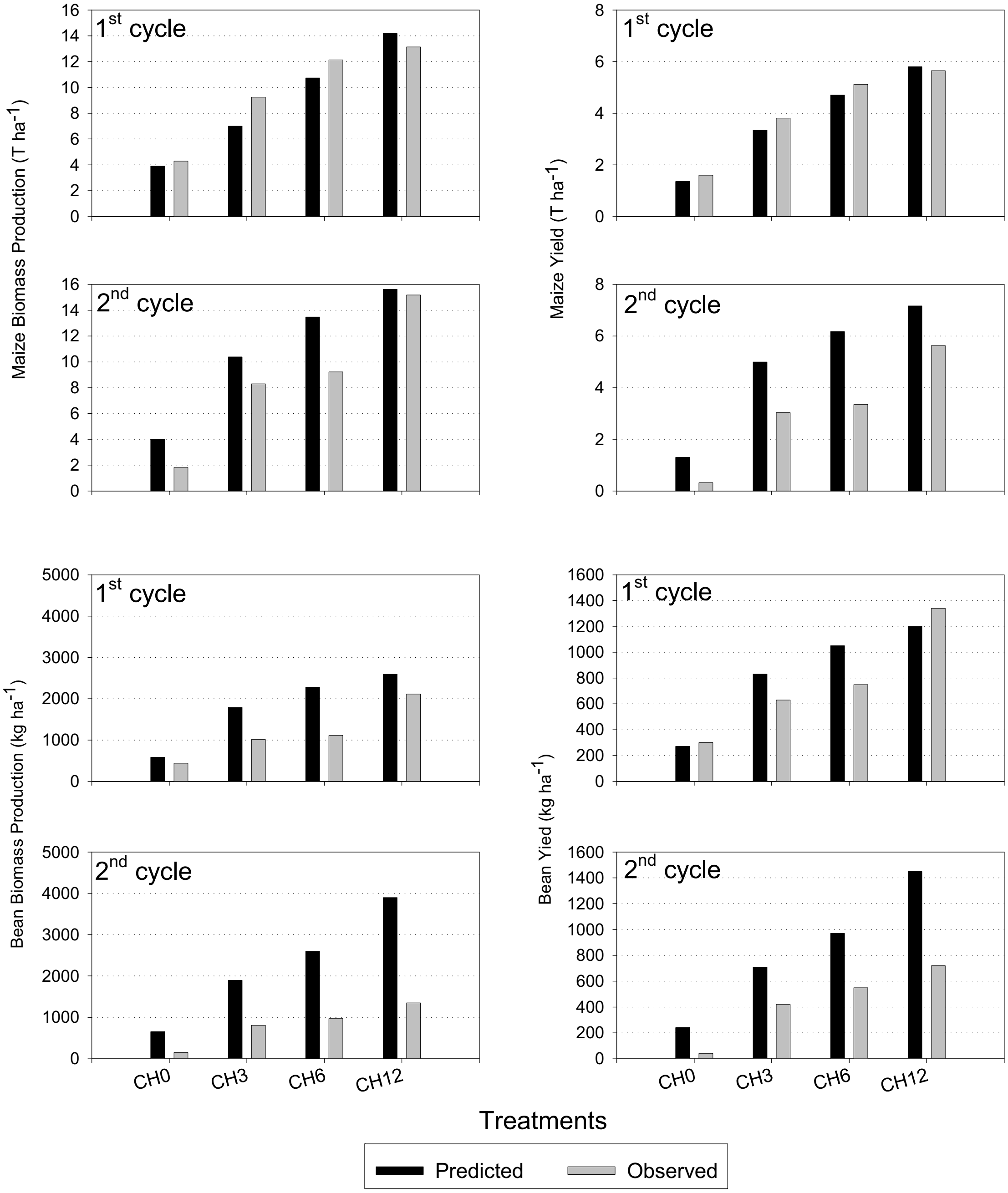

Figure 18. Predicted and observed yields of shoot biomass and grain for maize/bean rotation with different rates of chicken manure (CHME) in Pescador, Colombia.

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).

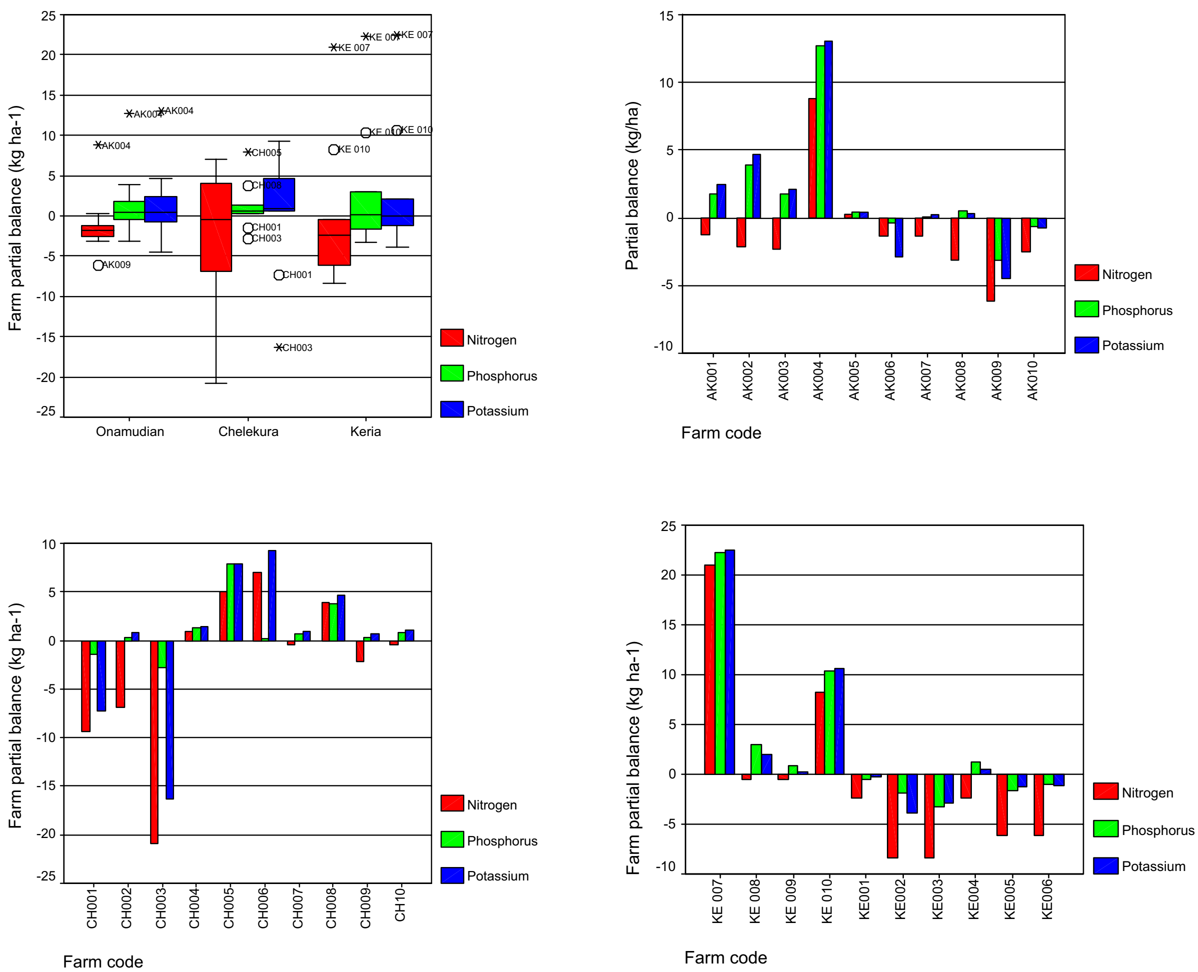

Figure 19. Mean partial nutrient balances by village (a), and farm level in the villages of Onamudian (b), Chelekura (c) and Keria (d)

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

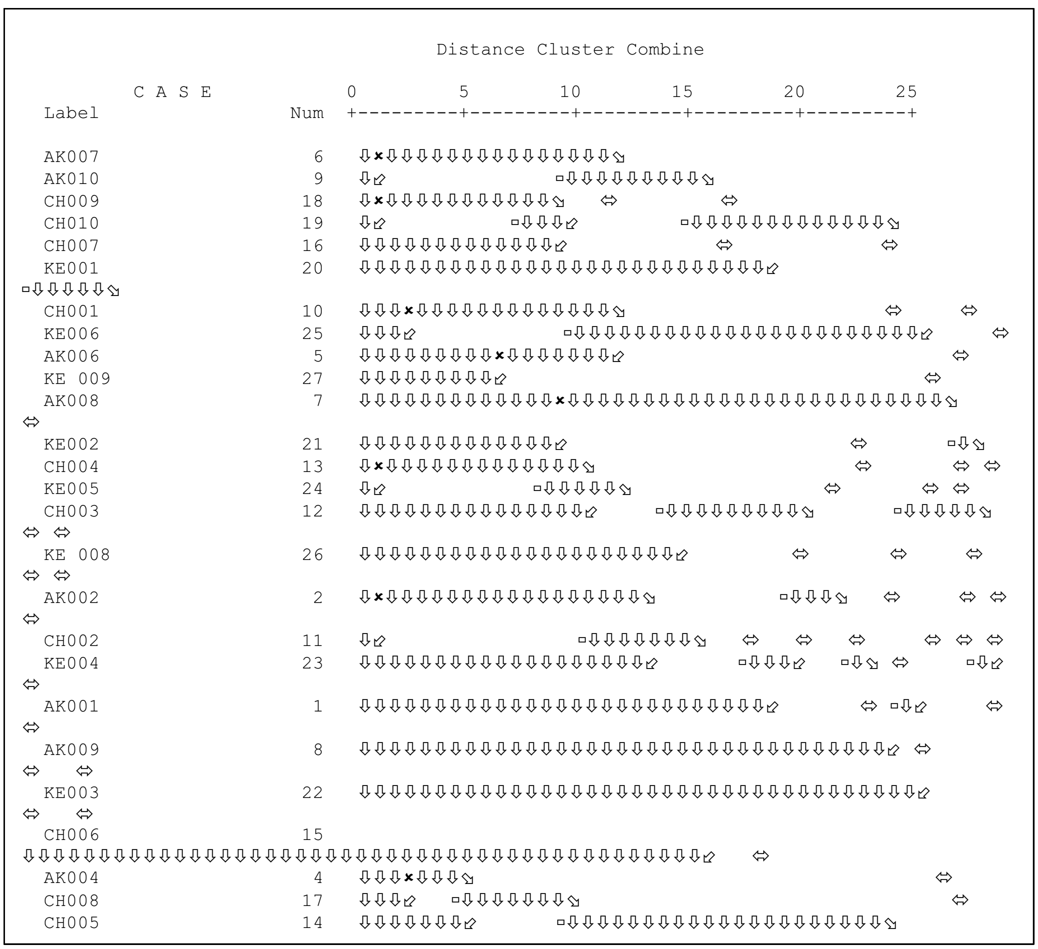

Figure 20. Average linkage dendrogram of farm data using the ochai coefficient

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)

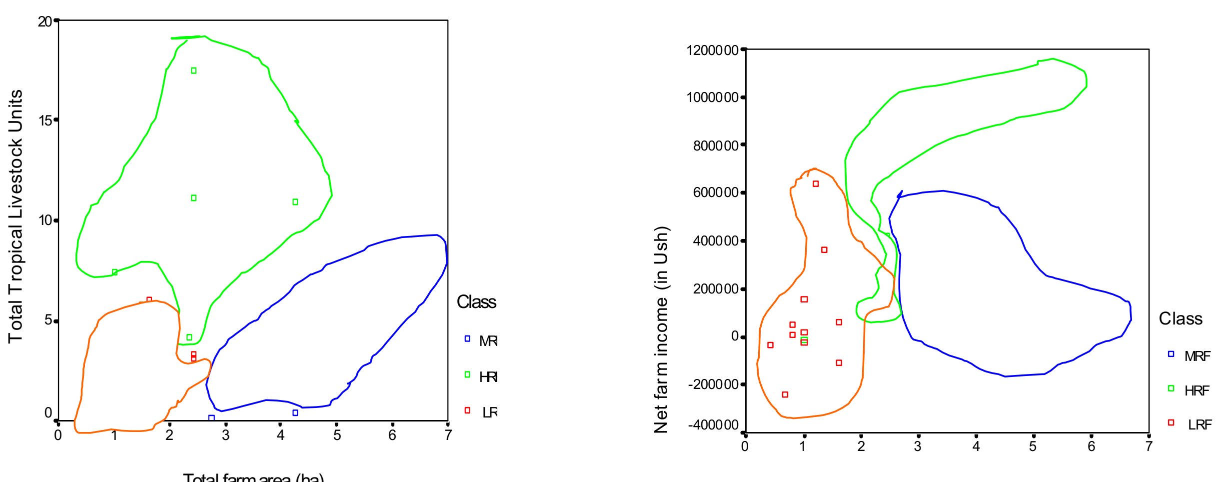

Figure 21. Farm clusters as determined by plots of (a) total tropical livestock units and total farm area and (b) net farm incomes and total farm area.

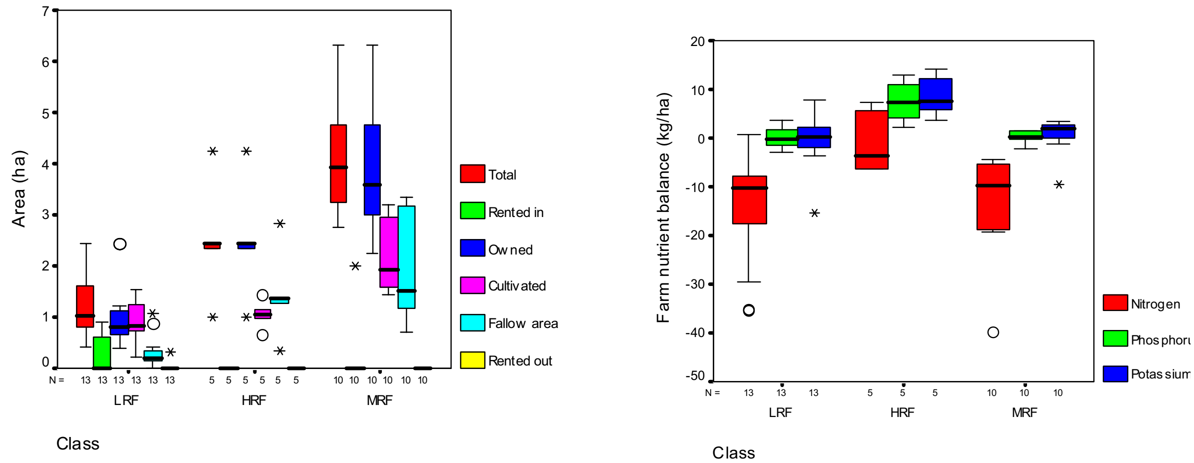

Figure 22. Total farm sizes and (a) land utilization and (b) farm nutrient balances by farm class.

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*

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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° 20' West, 11° 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.

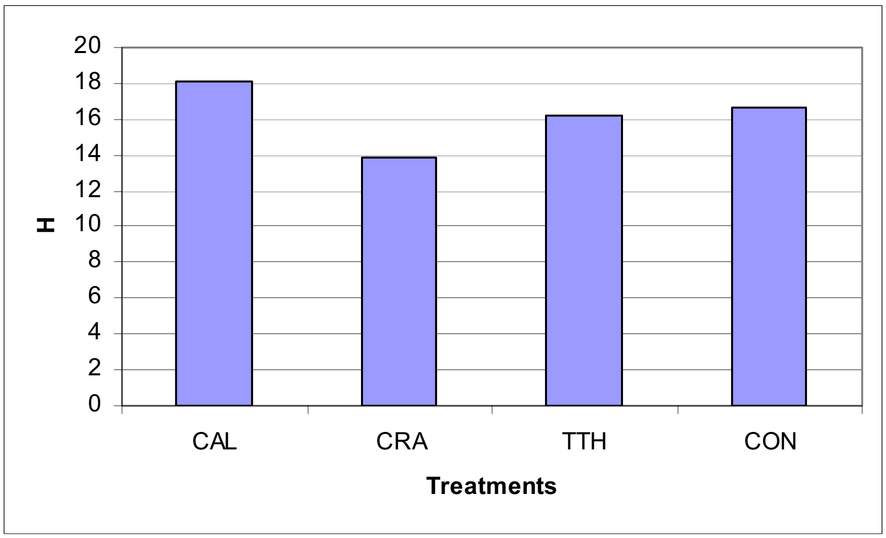

Figure 23. Diversity of soil-borne fungi in plots receiving or not receiving different sources of green manure. H represents the Shannon Wiener diversity index.

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.

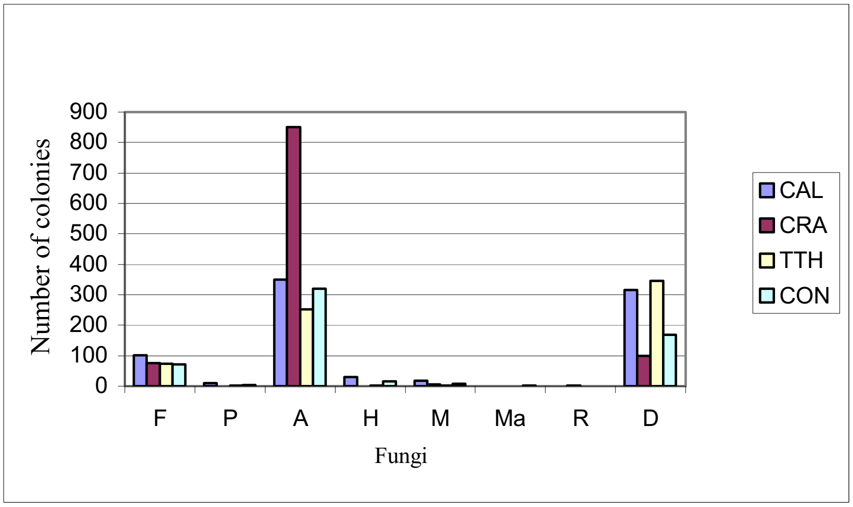

Figure 24. Frequency of different fungi isolated from plots receiving none (control) or a fast, intermediate and slow decomposing green manure or the control.

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.

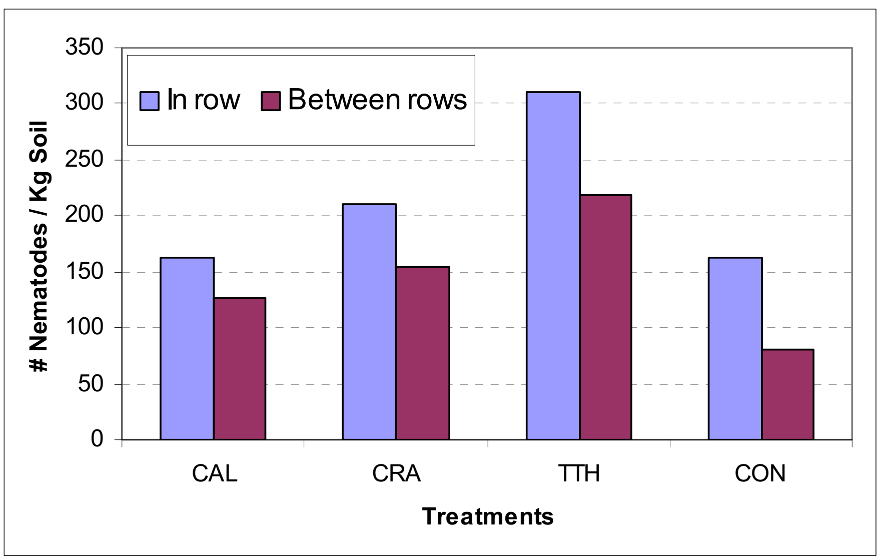

Figure 25. Total number of nematodes from plots receiving a fast, intermediate and slow decomposing green manure or the control

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.

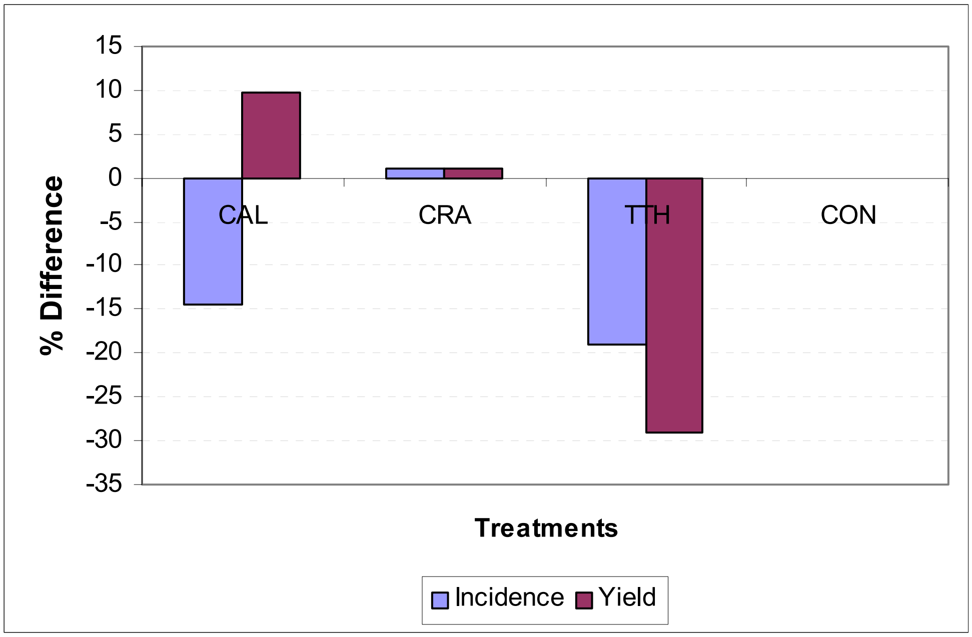

Figure 26. Incidence of root rots and yield of the bean genotype A 70, grown in plots with or without different types of green manures expressed as a percent of control treatment.

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

J.J. Ramisch[1], A. Muriuki[1], B. Vanlauwe[1], I. Ekise[1]; M.T. Misiko[2]; J. Okello[3]; J. Ogada[4]
[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.

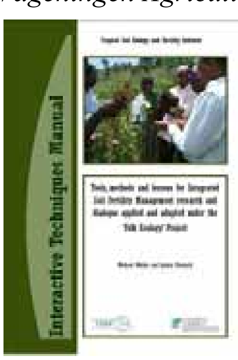
Activity 1.6 Methods for integrating and strengthening local and technical knowledge of soil processes, soil quality, ecosystem services and BGBD developed

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.

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

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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.

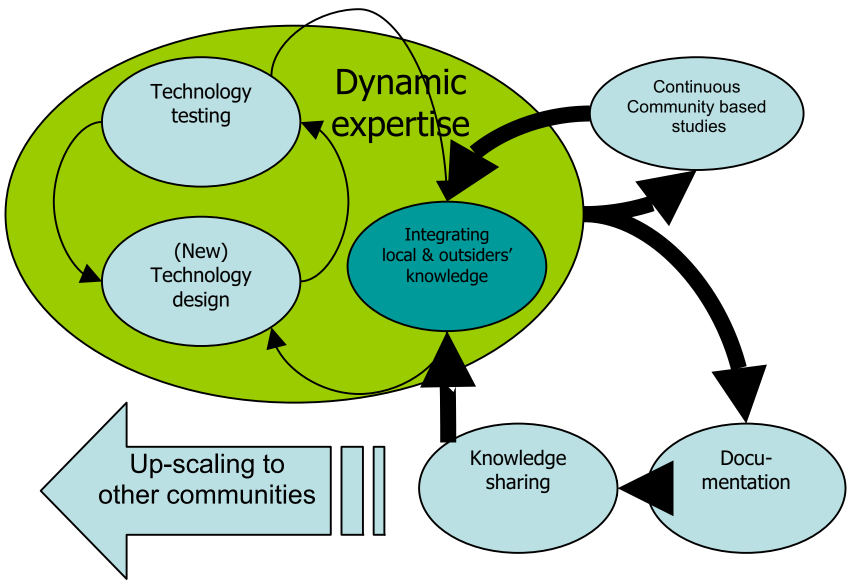

Figure 27. The Strengthening Folk Ecology process. Dialogue and group activities that form part of the "Integration of local and insiders' knowledge" feed into an iterative process of collective and individual technology design and testing, which leads to the generation of local "dynamic expertise" for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

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

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

Maithya, J.M[1], Kimenye, L.N[1], Mugivane, F. [1], Ramisch, J.[2]
[1]Department of Agricultural Economics, University of Nairobi; [2]TSBF-CIAT

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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[1]Kenya Agricultural Research Institute (KARI), [2]University of Nairobi (UON), [3]TSBF-CIAT.

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).