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

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Rationale

Sustainable agriculture is viewed here from a systems perspective in which the agroecosystem interacts with the atmospheric system and the hydrological cycle as well as with the social and economic systems of the community where it is practiced. This conceptual model transcends the classical boundaries of the biophysical sciences and requires integration with economics, sociology, anthropology and political science. In this context, Output 1 contributes towards developing a mechanistic understanding of the physical, chemical and biological processes regulating soil fertility as a result of intensification and diversification of cropping systems and the recuperation of degraded lands. Nutrient cycling and organic matter dynamics are undoubtedly key drivers of agroecosystem function and 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.

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

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

Key research questions:

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

Highlights

- In a set of trials in western Kenya, evaluating the performance of various classes of legumes as affected by soil fertility status, agro-ecological conditions, and P application on legume grain yield, biological nitrogen fixation and shoot N accumulation, N_2-fixation and net N inputs differed significantly with rainfall and soil fertility status. Mean N_2-fixation by green manure legumes ranged from 319 kg ha^{-1} (velvet bean) to 29 kg ha^{-1} (jackbean). For the forage legumes, mean N_2-fixation ranged from 97 kg N ha^{-1} for desmodium to 39 kg N ha^{-1} for siratro, while for the grain legumes, the range was from 172 kg N ha^{-1} for lablab to 3 kg N ha^{-1} for soyabean without P. Lablab and groundnut showed consistently greater N_2-fixation and net N inputs across agro-ecological and soil fertility gradients. The results demonstrate differential contributions of the green manure, forage and grain legume species to soil fertility improvement in different biophysical niches in smallholder farming systems and suggest that appropriate selection is needed to match species with the niches and farmers' needs.

- In a trial in Zimbabwe on two contrasting soil types, evaluating the impact of organic resource quality on maize productivity and soil mineral N dynamics, early season soil mineral N availability was the primary regulatory factor for maize productivity obtainable under poor sandy soils. Maize biomass at 2 weeks after planting was a potential tool for early season assessment of potential yields under constrained environments.

- Soybean accessions were significantly different in their ability to stimulate *Striga hermonthica* seed germination with some soybean accessions showing a higher germination potential than *Desmodium* and *Mucuna*. Seeds of *Striga*, treated with strigol, a chemical that stimulates *Striga* germination, displayed high germination rates, which was not significantly different from stimulation due to soybean accessions like TGX1448-2E and TGX1740-2F. Pot trials clearly confirmed some of the trends observed in above laboratory tests and confirm the existence of large variation in suicidal germination potential of different soybean varieties.

- Improved (TGX) and local varieties of soybeans were assessed through farmer's participatory approaches for suitability for production in different environments in Kenya. These varieties were further evaluated using their protein, oil and physical properties (colour and weight of 100 corns). Most of the varieties in this screening exercise were good for home consumption and the local variety (Nyala) and the improved one (Maksoy 4M) were ideal for industrial use based on grain size as the indicator. However, the yields from Nyala are generally low and only can be used if the TGX varieties were crossed with them to improve their yield.

- In Western Kenya, on P-deficient soils, a more efficient P management strategy would be to apply small amount of P to each crop. Use of large doses of P such as 250 kg P ha^{-1} with or without seasonal additions of P may in the long term be expensive to the farmers and thus the cost effectiveness of application of these large amounts must be compared to the low rates with or without seasonal additions. Preliminary findings based on modeling indicated that labile P pools decreased with cropping period due to net transfer to the stable pool and crop uptake.

- Farmer participatory approach was used to evaluate improved soybean varieties to identify the varieties that are suited to different environments in Kenya and thus enhance the effectiveness of recommendations through widespread adoption.

- In Mozambique, the participatory camera methodology proved a valuable tool for providing further insights into group dynamics, empowerment and shared decision making around linking farmers to markets.

- In Mozambique, results demonstrate that some benefits of social capital are not equally distributed, and in some cases create competitive advantage, more than public goods. There are significant differences based on gender, position within groups and educational levels, with male group members and the more educated benefiting more.

- In Zimbabwe, field results showed that blanket fertilizer recommendations are of limited relevance for heterogeneous smallholder farms. Targeted application of mineral fertilizers and manure according to soil type and past management of fields is imperative for improving crop yields and nutrient use efficiencies.

- In Zimbabwe, results showed the essential role of manure in sustaining and replenishing soil fertility on smallholder farms through its multiple effects. Manure may not supply sufficient amounts of N required by crops, whilst mineral N and P fertilizers alone do not supply other essential nutrients and may lead to soil acidification. Integrated use of mineral N and P fertilizers and manure is therefore required for sustainable crop production and soil fertility management on smallholder farms in sub-Saharan Africa.

- Showed that biological nitrification inhibition (BNI) may be widespread among plants with significant inter- and intra-specific variability and suggested that this genetically controlled BNI function could have the potential to be managed and/or introduced into pasture grasses/crops that do not exhibit the phenomenon via genetic improvement approaches that combine high productivity with the capacity to regulate soil nitrification.

- Screened 43 accessions of *Brachiaria humidicola* for specific and total biological nitrification inhibitory (BNI) activity and quantified genetic diversity in BNI and identified contrasting accessions with very high (CIAT 26573) and low BNI activity (CIAT 16880).

- Field studies after four cycles of analyses for BNI activity indicated that nitrification rates were lower with the two accessions of *Brachiaria humidicola* than the accession of *Panicum maximum*. A highly sensitive soil incubation method to estimate nitrite formation was tested and adapted to detect even small differences in nitrification rates among the grasses.

- Showed that the PCR technique developed is precise and reproducible for monitoring biological nitrification inhibition activity through soil bacterial populations of ammonium oxidizing bacteria and *Archaea*.

- Showed that soil organisms are extremely diverse and contribute to a wide range of 'soil based'ecosystem services that are essential to the sustainable function of natural and managed ecosystems.

- A participatory approach and a methodological guide were developed to identify and classify local indicators of soil quality and relate them to technical soil parameters, and thus develop a common language between farmers, extension workers and scientists. Development of local capacities for consensus building constitute 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 scales.

- Showed that mixing prunings of multipurpose trees and shrubs (MPT) materials with contrasting quality is an effective way to modify aerobic N release pattern as well as apparent anaerobic N degradation and could possibly be applied to minimize N losses in the rumen and in the soil. In addition, apparent anaerobic N degradation was identified as good predictor of aerobic N release in the soil, which has resource saving implications when screening MTP to be used as green manures.

- A methodological approach was developed in which the origin of soil aggregates separated according to visual criteria could be determined by comparing their specific organic matter signatures assessed by Near Infrared Spectrometry (NIRS) to signatures of biogenic structures produced by soil ecosystem engineers (invertebrates and roots) living in the same soil.

- Compared differences in soil phosphorus fractions between large earthworm casts and surrounding soils in 10 year-old upland agroforestry system, pasture, and secondary forest in the Central Brazilian Amazon and found that earthworm casts had higher levels of organic hydroxide P than surrounding soils.
- Showed the potential of bio-char applications to improve N input into agroecosystems throught improvement in biological nitrogen fixation.

Output target 2007

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

Published work

Schlecht[1], E., Buerkert[2], A., Tielkes[3], E. and Bationo[3], A. (2006) A critical analysis of challenges and opportunities for soil fertility restoration in Sudano-Sahelian West Africa. Nutrient Cycling in Agroecosystems 76: 109-136

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Abstract: Since the 1970s, research throughout West Africa showed that low soil organic matter and limited availability of plant nutrients, in particular phosphorus and nitrogen, are major bottlenecks to agricultural productivity, which is further hampered by substantial topsoil losses through wind and water erosion. A few widely recognized publications pointing to massive nutrient mining of the existing crop-livestock production systems triggered numerous studies on a wide array of management strategies and policies suited to improve soil fertility. Throughout West Africa, the application of crop residue mulch, animal manure, rock phosphates and soluble mineral fertilizers have been shown to enhance crop yields, whereby yield increases varied with the agro-ecological setting and the rates of amendments applied. In more humid areas of Western Africa, the intercropping of cereals with herbaceous or ligneous leguminous species, the installation of fodder banks for increased livestock and manure production, and composting of organic material also proved beneficial to crop production. However, there is evidence that the low adoption of improved management strategies and the lack of long-term investments in soil fertility can be ascribed to low product prices for agricultural commodities, immediate cash needs, risk aversion and labour shortage of small-scale farmers across the region. The wealth of knowledge gathered during several decades of on-station and on-farm experimentation calls for an integration of these data into a database to serve as input variables for models geared towards ex-ante assessment of the suitability of technologies and policies at the scale of farms, communities and regions. Several modeling approaches exist that can be exploited in this sense. Yet, they have to be improved in their ability to account for agro-ecological and socio-economic differences at various geographical scales and for residual effects of management options, thereby allowing scenario analysis and guiding further fundamental and participatory research, extension and political counselling.

Pypers[1], P., Delrue[2], J., Diels[2], J., Smolders[2], E. and Merckx[2], R. (2006) Phosphorus intensity determines short-term P uptake by pigeon pea (*Cajanus cajan* L.) grown in soils with differing P buffering capacity. Plant & Soil 284: 217-227

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Abstract: Phosphorus (P) uptake by plant roots depends on P intensity (I) and P quantity (Q) in the soil. The relative importance of Q and I on P uptake is unknown for soils with large P sorption capacities because of difficulties in determining trace levels of P in the soil solution. We applied a new isotope based method to detect low P concentrations (< 20 µg P l^{-1}). The Q factor was determined by assessment of the isotopically exchangeable P in the soil (E-value) and the I factor was determined by measurement of the P concentration in the pore water. A pot trial was set up using four soils with similar labile P quantities but contrasting P buffering capacities. Soils were amended with KH_2PO_4 at various rates and pigeon pea (*Cajanus cajan* L.) was grown for 25 days. The P intensity ranged between 0.0008 and 50 mg P l^{-1} and the P quantity ranged between 10 and 500 mg P kg^{-1}. Shoot dry matter (DM) yield and P uptake significantly increased with increasing P application rates in all soils. Shoot DM yield and P uptake, relative to the maximal yield or P uptake, were better correlated with the P concentration in the pore water (R^2=0.83–0.90) than with the E-value (R^2=0.40–0.53). The observed P uptakes were strongly correlated to values simulated using a mechanistic rhizosphere model (NST 3.0). A sensitivity analysis reveals that the effect of P intensity on the short-term P uptake by pigeon pea exceeded the effect of P quantity both at

low and high P levels. However, DM yield and P uptake at a given P intensity consistently increased with increasing P buffering capacity (PBC). The experimental data showed that the intensity yielding 80% of the maximal P uptake was 4 times larger in the soil with the smallest PBC compared to the soil with the largest PBC. This study confirms that short-term P uptake by legumes is principally controlled by the P intensity in the soil, but is to a large extent also affected by the PBC of the soil.

Pypers[1], P.,Van Loon[2], L., Diels[2], J., Abaidoo[3], R., Smolders[2], E. and Merckx[2], R. (2006) Plant-available P for maize and cowpea in P-deficient soils from the Nigerian Northern Guinea savanna – comparison of *E*- and *L*-values. Plant & Soil 283: 251-264

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Abstract: There are several indications that legumes are capable of accessing sparingly soluble phosphorus (P) in the soil through root-induced processes. We hypothesize that this plant-induced mobilization of P can be demonstrated if the plant accessible P assessed by isotopic dilution ('L-value') exceeds the corresponding values assessed in soil extracts ('E-values'). A greenhouse experiment was set up to assess if L/E ratios are affected by P supply and by crop type. The L- and E-values were determined in three P-deficient soils of the Nigerian Northern Guinea savanna (NGS), applied with various rates of TSP, for two cowpea varieties (*Vigna unguiculata* L., cv Dan-Ila and cv IT-82D-716) and maize (*Zea mays* L., cv. Oba Super I) as a reference. Plants grown in control soils were severely P-deficient. Plant growth and shoot P uptake significantly increased with increasing P application in all three soils and for all crops, but relative yield and shoot-P responses to P application were similar between maize and cowpea. Both L- and E-values increased with increasing P application. Average L/E ratios for maize were 1.4±0.3 and were unaffected by the P application. For cowpea in contrast, L/E ratios were 3.1±0.2 (significantly larger than one) in one of the three control soils and significantly decreased to 1.3±0.1 at largest P supply. Elevated L/E ratios in cowpea were not associated with an increase in P uptake compared to the other two control soils in which no increase in L/E ratio was observed. It is concluded that cowpea is able to access non-labile P under P-deficient conditions. However, this process cannot overcome P deficiency in these soils, probably because P uptake is limited by the small P concentration in the soil solution (1–2 µg P l^{-1}) and this limitation is not overcome by an increase in the accessible soil P quantity (L-value).

Zingore[1,2], S., Murwira[1], H.K., Delve[1], R.J. and Giller[2], K.E. (2007) Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. Agriculture, Ecosystems and Environment 119: 112-126

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Abstract: An improved understanding of soil fertility variability and farmers' resource use strategies is required for targeting soil fertility improving technologies to different niches within farms. We measured the variability of soil fertility with distance from homesteads on smallholder farms of different socio-economic groups on two soil types, granite sand and red clay, in Murewa, northeast Zimbabwe. Soil organic matter, available P and CEC decreased with distance from homestead on most farms. Available P was most responsive to management, irrespective of soil type, as it was more concentrated on the plots closest to homesteads on wealthy farms (8 to 13 mg kg^{-1}), compared with plots further from homesteads and all plots on poor farms (2-6 mg kg^{-1}). There was a large gap in amounts of mineral fertilizers used by the wealthiest farmers (>100 kg N and > 15 kg P per farm; 39 kg N ha^{-1} and 7 kg P ha^{-1}) and the poorest farmers (<20 kg N and <10 kg P per farm; 19 kg N ha^{-1} and 4 kg P ha^{-1}). The wealthy farmers who owned cattle also used large amounts of manure, which provided at least 90 kg N and 25 kg P per farm per year (36 kg N ha^{-1} and 10 kg P ha^{-1}). The poor farmers used little or no organic sources of nutrients. The wealthiest farmers distributed mineral fertilizers evenly across their farms, but preferentially targeted manure to the plots closest to the homesteads, which received about 70 kg N and 18 kg P per plot from manure compared with 20 kg N and 8 kg P per plot on the mid-fields, and 10 kg N and 2 kg P per plot (76 kg N ha^{-1} and 21 kg P ha^{-1}) from manure compared with 23 kg N and 9 kg P per plot on the midfields (26 kg N ha^{-1} and 10 kg P ha^{-1}), and 10 kg N and 1 kg P per plot (and ha^{-1}) on the outfields. Crop allocation on

the home fields was most diversified on the wealthiest farms where maize was allocated 41% of the area followed by grain legumes (24%) and paprika (21%). Maize was allocated at least 83% of the homefields on farms with less access to resources. All the farmers invariably applied nutrients to maize but little to groundnut. Maize grain yields were largest on the homefields on the wealthy farms (2.7 – 5.0 t ha^{-1}), but poor across all fields on the poor farms (0.3 - 1.9 t ha^{-1}). Groundnut grain yields showed little difference between farms and plots. N and P partial balances were largest on the wealthy farms, although these fluctuated from season to season (–20 to +80 kg N per farm and 15 - 30 kg P per farm; average 21 kg N ha^{-1} and 8 kg P ha^{-1}). The partial balances on the wealthy farms were largest on the homefield (20 - 30 kg N and 13 kg P per plot; >26 kg N ha^{-1} and 13 kg P ha^{-1}), but decreased to 10 – 20 N and 6 – 9 kg P per plot (<20 kg N ha^{-1} and 13 kg P ha^{-1}) in midfields and –7 to +10 kg N and –1 to +1 kg P per plot (<10 kg N ha^{-1} and <2 kg P ha^{-1}) in the outfields. N and P balances differed little across plots on the poor farms (-2 to +4 kg per plot;–5 to +4 kg ha^{-1}) due to limited nutrients applied and small off-take from small harvests. This study highlights the need to consider soil fertility gradients and the nutrient management patterns creating them when designing options to improve resource use efficiency on smallholder farms.

Zingore[1,2], S., Murwira[1], H.K., Delve[1], R.J. and Giller[2], K.E. (2007) Soil type, historical management and current resource allocation: three dimensions regulating variability of maize yields and nutrient use efficiencies on smallholder farms. Field Crops Research 101: 296 - 305
[1]TSBF-CIAT, Zimbabwe; [2]Wageningen University, the Netherlands
Abstract: Soil fertility varies markedly within and between African smallholder farms, both as a consequence of inherent factors and differential management. Fields closest to homesteads (homefields) typically receive most nutrients and are more fertile than outlying fields (outfields), with implications for crop production and nutrient use efficiencies. Maize yields following application of 100 kg N ha^{-1} and different rates and sources of P were assessed on homefields and outfields of small holder farms in Zimbabwe. Soil organic carbon, available P and exchangeable bases were greater on the homefields than the outfields. In each of three experimental seasons, maize yields in homefield control plots were greater than in the outfields of farms on a granitic sandy and red-clay soil. Application of mineral N significantly increased maize yields on home fields in the first season (2.1-3.0 t ha^{-1} on the clay soil and 1.0-1.5 t ha^{-1} on the sandy soil) but the effects of N alone were not significant on the outfields due to other yield-limiting factors. Greatest yields of about 6 t ha^{-1} were achieved on the clayey home field with 100 kg N ha^{-1} and 30 kg P ha^{-1} applied as single super phosphate (SSP). Manure application gave greater yields (3-4 t ha^{-1}) than SSP (2-3 t ha^{-1}) in the sandy home field and in the clayey outfield. Maize did not respond significantly to N, dolomitic lime, manure and P on the sandy outfield in the first and second seasons. In the third season, manure application (17 t manure ha^{-1} $year^{-1}$) on the sandy outfield did result in a significant response in grain yields. Apparent P recovery in the first season was 55-65% when P was applied at 10 kg ha^{-1} on the clayey home field (SSP), clayey outfield (SSP and manure) and sandy home field (manure) with apparent P recovery less than 40% when P was applied at 30 kg ha^{-1}. On the sandy outfield, P recovery was initially poor (<20%), but increased in the successive seasons with manure application. In a second experiment, less than 60 kg N ha^{-1} was required to attain at least 90% of the maximum yields of 2-3 t ha^{-1} on the sandy home field and clayey outfield. N use efficiency varied from >50 kg grain kg-1 N on the infields, to less than 5 kg grain kg^{-1} N on the sandy outfields. Apparent N recovery efficiency by maize was greatest at small N application rates with applied. We concluded that blanket fertilizer recommendations are of limited relevance for heterogeneous small holder farms. Targeted application of mineral fertilizers and manure according to soil type and past management of fields is imperative for improving crop yields and nutrient use efficiencies.

Subbarao[1], G.V., Ito[1], O., Sahrawat[2], K.L., Berry[3], W.L., Nakahara[4], K., Ishikawa[4], T., Watanabe[4], T., Suenaga[5], K., Rondon[6], M. and Rao[6], I.M. (2006) Scope and strategies for regulation of nitrification in agricultural systems – Challenges and opportunities. Critical Reviews in Plant Sciences 25: 303-335

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Abstract: Nitrification, a microbial process, is a key component and integral part of the nitrogen (N) cycle. Soil N is in a constant state of flux, moving and changing chemical forms. During nitrification, a relatively immobile N-form (NH_4^+) is converted into highly mobile nitrate-N (NO^-_3). The nitrate formed is susceptible to losses via leaching and conversion to gaseous forms via denitrification. Often less than 30% of the applied N fertilizer is recovered in intensive agricultural systems, largely due to losses associated with and following nitrification. Nitrogen-use efficiency (NUE) is defined as the biomass produced per unit of assimilated N and is a conservative function in most biological systems. A better alternative is to define NUE as the dry matter produced per unit N applied and strive for improvements in agronomic yields through N recovery. Suppressing nitrification along with its associated N losses is potentially a key part in any strategy to improve N recovery and agronomic NUE. In many mature N-limited ecosystems, nitrification is reduced to a relatively minor flux. In such systems there is a high degree of internal N cycling with minimal loss of N. In contrast, in most high-production agricultural systems nitrification is a major process in N cycling with the resulting N losses and inefficiencies. This review presents the current state of knowledge on nitrification and associated N losses, and discusses strategies for controlling nitrification in agricultural systems. Limitations of the currently available nitrification inhibitors are highlighted. The concept of biological nitrification inhibition (BNI) is proposed for controlling nitrification in agricultural systems utilizing traits found in natural ecosystems. It is emphasized that suppression of nitrification in agricultural systems is a critical step required for improving agronomic NUE and maintaining environmental quality.

Completed work

Variable grain legume yields, responses to phosphorus and rotational effects on maize across soil fertility gradients on African smallholder farms.

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Soil fertility varies markedly within and between African smallholder farms, both as a consequence of inherent factors and differential management. Fields closest to homesteads (homefields) typically receive most nutrients and are more fertile than outlying fields (outfields), with implications for crop production and nutrient use efficiencies. Maize yields following application of 100 kg N ha^{-1} and different rates and sources of P were assessed on homefields and outfields of smallholder farms in Zimbabwe. Soil organic carbon, available P and exchangeable bases were greater on the homefields than outfields. In each of three experimental seasons, maize yields in homefield control plots were greater than in the outfields of farms on a granitic sandy and a red-clay soil. Application of mineral N significantly increased maize yields on homefields in the first season (2.1 to 3.0 t ha^{-1} on the clay soil and 1.0 to 1.5 t ha^{-1} on the sandy soil) but the effects of N alone were not significant on the outfields due to other yield-limiting factors. Greatest yields of about 6 t ha^{-1} were achieved on the clayey homefield with 100 kg N ha^{-1} and 30 P kg ha^{-1} applied as single super phosphate (SSP). Manure application gave greater yields (3-4 t ha^{-1}) than SSP (2-3 t ha^{-1}) in the sandy homefield and in the clayey outfield. Maize did not respond significantly to N, dolomitic lime, manure and P on the sandy outfield in the first and second seasons. In the third season, manure application (~17 t manure ha^{-1} yr^{-1}) on the sandy outfield did result in a significant response in grain yields. Apparent P recovery in the first season was 55 - 65% when P was applied at 10 kg ha^{-1} on the clayey homefield (SSP), clayey outfield (SSP and manure) and sandy homefield (manure) with apparent P recovery less than 40% when P was applied at 30 kg ha^{-1}. On the sandy outfield, P recovery was initially poor (<20%), but increased in the successive seasons with manure application. In a second experiment, less than 60 kg N ha^{-1} was required to attain at least 90% of the maximum yields of 2-3 t ha^{-1} on the sandy homefield and clayey outfield. N use efficiency varied from >50 kg grain kg^{-1} N on the infields, to less than 5 kg grain kg^{-1} N on the sandy outfields. Apparent N recovery efficiency by maize was greatest at small N application rates with P applied. We conclude that blanket fertilizer recommendations are of limited relevance for heterogeneous smallholder farms. Targeted application of mineral fertilizers and manure according to soil type and past management of fields is imperative for improving crop yields and nutrient use efficiencies.

Niche-based assessment of contributions of legumes to the nitrogen economy of Western Kenya smallholder farms.

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Abstract: Nitrogen (N) deficiency is a major constraint to the productivity of the African smallholder farming systems. Grain, green manure and forage legumes have the potential to improve the soil N fertility of smallholder farming .systems through biological N_2-fixation. The N_2-fixation of bean (*Phaseolus vulgaris*), soybean (*Glycine max*), groundnut (*Arachis hypogaea*), lima bean (*Phaseolus lunatus*), lablab (*Lablab purpureus*), velvet bean (*Mucuna pruriens*), crotalaria (*Crotalaria ochroleuca*), jackbean (*Canavalia ensiformis*), desmodium (*Desmodium uncinatum*), stylo (*Stylosanthes guianensis*) and siratro (*Macroptilium atropurpureum*) was assessed using the ^{15}N natural abundance method. The experiments were conducted at three sites in western Kenya, selected on an agro-ecological zone (AEZ) gradient defined by rainfall. On a relative scale, Museno represents high potential AEZ 1, Majengo medium potential AEZ 2 and Ndori low potential AEZ 3. Rainfall in the year of experimentation was highest in AEZ 2, followed by AEZ 1 and AEZ 3. Experimental fields were classified into high, medium and low fertility classes, to assess the influence of soil fertility on N_2-fixation performance. The legumes were planted with triple super phosphate (TSP) at 30 kg P ha^{-1}, with an extra soyabean plot planted without TSP (soyabean-P), to assess response to P, and no artificial inoculation was done. Legume grain yield, shoot N accumulation, %N derived from N_2-fixation, N_2-fixation and net N inputs differed significantly ($P<0.01$) with rainfall and soil fertility. Mean grain yield ranged from 0.86 Mg ha^{-1}, in AEZ 2, to 0.30 Mg ha^{-1}, in AEZ 3, and from 0.78 Mg ha^{-1}, in the high fertility field, to 0.48 Mg ha^{-1}, in the low fertility field. Shoot N accumulation ranged from a maximum of 486 kg N ha^{-1} in AEZ 2, to a minimum of 10 kg N ha^{-1} in AEZ 3. Based on shoot biomass estimates, the species fixed 25– 90% of their N requirements in AEZ 2, 23–90% in AEZ 1, and 7–77% in AEZ 3. Mean N_2- fixation by green manure legumes ranged from 319 kg ha^{-1} (velvet bean) in AEZ 2 to 29 kg ha^{-1} (jackbean) in AEZ 3. For the forage legumes, mean N_2-fixation ranged from 97 kg N ha^{-1} for desmodium in AEZ 2 to 39 kg N ha^{-1} for siratro in AEZ 3, while for the grain legumes, the range was from 172 kg N ha^{-1} for lablab in AEZ 1 to 3 kg N ha^{-1} for soybean-P in AEZ 3. Lablab and groundnut showed consistently greater N_2-fixation and net N inputs across agro-ecological and soil fertility gradients. The use of maize as reference crop resulted in lower N_2-fixation values than when broad-leaved weed plants were used. The results demonstrate differential contributions of the green manure, forage and grain legume species to soil fertility improvement in different biophysical niches in smallholder farming systems and suggest that appropriate selection is needed to match species with the niches and farmers' needs.

Multiple benefits of manure: the key to maintenance of soil fertility and restoration of depleted sandy soils on African smallholder farms

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Manure is a key nutrient resource on smallholder farms in the tropics, especially on poorly buffered sandy soils, due to its multiple benefits for soil fertility. Smallholder farms in Africa consist of multiple fields that are managed differently, which leads to steep gradients of soil fertility within farms. Farmers preferentially apply manure to fields closest to homesteads (homefields), which are consequently more

fertile than fields further away from homesteads (outfields). Chemical measurements were made on soils from four fields, a homefield and an outfield of a farm located on a sandy soil and the same on a farm on a clay soil, in order to assess the long-term effects of manure use. Soils from these fields were again sampled for analysis from experimental plots after maize was grown for three years with mineral N fertilizer application in combination with manure or mineral P. Nutrient addition experiments in pots in the greenhouse were used to identify limiting nutrients for growth of maize and to investigate the capacity of manure to supply N, P, bases and micronutrients. The sandy and clayey homefields were initially more fertile than the outfields on a similar soil type. Addition of about 17 t ha^{-1} manure in combination with ammonium nitrate (100 kg N ha^{-1}) for three successive seasons significantly increased soil organic carbon (SOC) by up to 63%, pH by 0.2 units, available P by 8 mg kg^{-1} and base saturation by 20% on the sandy outfield. Sole N as ammonium nitrate (100 kg N ha^{-1}) or in combination with SSP led to acidification of the sandy soils, with a decrease of up 0.8 pH units after three seasons. In the greenhouse experiment, N and Ca were identified as deficient on the sandy homefield, while N, P, calcium (Ca) and zinc (Zn) were deficient or low on the sandy outfield. On the sandy outfield, addition of manure significantly increased the maize shoot biomass and the concentrations of Ca and Zn, but depressed the concentration of N. No nutrient deficiencies were detected on the clayey homefield, whilst P was deficient on the clayey outfield. This study highlights the essential role of manure in sustaining and replenishing soil fertility on smallholder farms through its multiple effects. Manure may not supply sufficient amounts of N required by crops, whilst mineral N and P fertilizers alone do not supply other essential nutrients and may lead to soil acidification. Integrated use of mineral N and P fertilizers and manure is therefore required for sustainable crop production and soil fertility management on smallholder farms in sub-Saharan Africa.

Does the enhanced P acquisition by maize following legumes in a rotation result from improved soil P availability?

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Field data have suggested that under P-deficient conditions, legumes supplied with phosphate rock (PR) increase P acquisition by a subsequent maize crop compared to direct application of PR to maize. This study assessed the mechanism of this positive rotational effect in terms of soil P availability using a greenhouse trial with large volume (74 l) containers. The rotation effect was analysed in relation to PR application, previous legume growth and incorporation of the legume residues. Velvet bean (*Mucuna pruriens*) and maize were grown in a representative Acrisol from the Nigerian Northern Guinea savannah. All soils were applied with sufficient urea to exclude N-effects in the rotations. In a first season, velvet bean and maize responded similarly to PR application, and P uptake by both crops increased by 45%. The soil total labile P quantity (E-value) and P concentration in soil solution (31P solution) after plant growth were increased by PR-application only in soils previously grown by the legume, demonstrating its capacity to mobilize PR. In the subsequent season, grain yields and P uptake of a maize crop following velvet bean were twice as large compared to maize following a first maize crop. This residual effect of velvet bean was even significant in treatments without PR-application, although both maize and velvet bean withdrew similar amounts of P during the first season and no differences in soil P availability were observed. Furthermore, legume residue incorporation in soils previously grown by maize did not affect yields or P uptake of the subsequent maize crop, while it significantly increased the E-value and 31P solution during the first 7 weeks in the second season. As such, the positive rotational effects of velvet bean were larger than predicted by soil P availability measures. Maize yield significantly increased with increasing plant P concentration among all treatments. However, the rotation effect was unrelated to internal P concentration: significantly larger yields were obtained for maize following velvet bean than for maize following maize at identical internal P. This suggested the presence of another growth-limiting, possibly soil biological factor which is counteracted by the previous velvet bean growth. In conclusion, our results confirmed that the introduction of a legume supplied with PR into a maize-based cropping system increases yield and P-uptake by a subsequent maize crop, compared to maize following a first

maize crop supplied with PR. These stimulations were, however, unrelated to improved P nutrition of the maize crop, but rather to other beneficial effects induced by the legume growth.

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

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

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

TSBF-CIAT is also empowering the farming communities on various methods of processing soybean for home utilization and household cash income – an important step to ensure sustainability. Since many past projects aimed at promoting soybean in East Africa (including Kenya) region could not result in the take off of soybean, TSBF-CIAT considered it crucial to carry out ex-ante analysis of the adoption potential of the new promiscuous soybean varieties in the farming systems of Kenya, essential before committing scarce resources in promoting adoption and other scaling out and scaling up activities.

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

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

This ex-ante result indicates that the improved soybean varieties (especially those selected by farmers in different locations) merit further attention and investment.

Improvement of low fertility soils (Oxisols) for high productivity and sustainability of crop-livestock systems in tropical savannas of Colombia

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The neotropical savannas of South America cover about 250 million hectares in Bolivia, Brazil, Colombia, Guyana, and Venezuela, and are connected with other important biomes, such as the Amazon Basin and the Chaco Region of Bolivia, Paraguay, and Argentina. Because of this proximity and, partly, because some of the soil resources are similar, the technology developed for the use of these savannas has influenced agronomic and land use practices applied in these other ecosystems. These savannas present one of the last major land areas with potential for agricultural production, and represent an area equivalent to the world's area of irrigated crop land.

There are enormous expectations in the international community for the use of this region - one of the few areas in the world available for immediate growth in food production. A great challenge thus exists in preserving natural resources while ensuring the sustainability of agricultural and livestock production. As world population continues growing the demand for food will increase and, because the productivity of some crops is reaching a plateau, there will be increasing pressure to bring any remaining lands into agricultural production. Thus it seems inevitable that more of the savanna lands will be exploited.

Lessons from the experience in the Brazilian Cerrados suggest that crop and pasture monocultures are not sustainable under the current management practices. The estimated rate of land degradation in the Cerrados is between 2%-4% per year. The causes of degradation of crop lands include soil compaction and erosion losses from inappropriate management practices, a rapid loss of soil organic matter, weed infestation, and pest and disease infestations. An example of the degree of anthropogenic intervention in the savanna agroecosystem is the fact that more than 12 million hectares are devoted to annual crops, many of which, such as maize and soybean, require high levels of external inputs, such as agrochemicals, energy, and management. Between 30 and 50 million hectares have been converted into monocropped pastures and most of them are under a process of degradation.

The challenge to achieve sustainable crop and livestock production systems is to generate technologies that can maintain high levels of productivity, while minimizing environmental risks. To achieve this it is necessary to overcome soil physical, chemical and biological limitations and to fight against soil degradation when subjected to monocropping, even under high-level of fertilizer applications. These processes are not well documented yet.

No-tillage, minimum tillage, and integrated crop/livestock systems are proving successful technologies in terms of farmer adoption. However, to ensure that, over the long term, these marginal savanna lands are being developed in a sustainable manner, we need to understand the principles and functioning of these systems; appreciate the social, cultural, and economic aspects involved; promote a favorable policy environment; and seek a clearer understanding of sustainability and its measurement. There is need to develop (1) alternative crop options that tolerate acid soil conditions, (2) better understanding of water and nutrient cycles, (3) principles of soil organic matter and crop residue management, and (4) improved biological management of soil fertility.

Major soil constraints for crop and pasture production in the Colombian savannas (Altillanura, 3.5 million hectares) are: (1) soil acidy and low nutrient availability, (2) high values of bulk density, (3) high susceptibility to erosion when loosened for planting crops and pastures, (4) weak soil structure; (5) low organic matter contents; (6)surface sealing; (7) low biological activity and biodiversity; (8) very low available water; (9) low infiltration capacity and, and (10) low hydraulic conductivity.

To make these soils productive it is necessary to improve their edaphic conditions to met the requirements of soil factors essential for good root growth, and therefore, for high crop production. Such soil growth factors are:

a) Presence and availability of essential nutrients;
b) Adequate aeration for roots and microorganisms;
c) Adequate available water;
d) Easy root penetration;
e) Rapid and uniform seed germination; and
f) Resistance of the soil to slaking, surface sealing and accelerated erosion.

A comparison between the soil constrains found in the Llanos, with the edaphic factors needed for good crop production, lead to the conclusion that these soils must be improved in terms of physical, chemical and biological conditions to make them productive and to move them to conservation agriculture (no-tillage) systems. This statement is supported by the results of two long-term experiments. To improve soils, experiments were established and from them the concept of building up an arable layer was developed. The arable layer concept proposed is based on combining: (1) adapted crop and forage germplasm; (2) vertical tillage to overcome soil physical constraints (high bulk density, surface sealing, low porosity, low water, infiltration rates, poor root penetration, etc.); (3) use of chemical amendments (lime and fertilizers) to enhance soil fertility; and (4) use of agropastoral systems to increase rooting, to promote soil biological activity, and to avoid soil repacking and compactation after tillage.

A set of field experiments were established in 1993 on a well drained silty clay loam soil (Tropeptic Haplustox Isohyperthermic Kaolinitic under native savanna at the Carimagua Experimental Station (4° 37' N, 71° 19' W, 175 m altitude) in the Eastern Plains (Llanos) of Colombia. It has a mean annual rainfall of 2240 mm and mean temperature of 27 °C. Soils have a pH of around 4.5, very low values of exchangeable Ca, Mg, K, and P and very high Al saturation (about 90%).

Treatments were arranged in the field using a split-plot design with four replications, in which alternative systems (in sub-plots, size 0.36 ha) were based on upland rice or maize (main plots). In phase I, the experiment included a high lime rate (2000 kg ha^{-1}) for maize production and 500 kg ha^{-1} for rice production according to crop requirements. Rice and maize-based systems are reported here. A rice and maize system was planted as: (1) rice monoculture; (2) rice in rotation with cowpea for grain); (3) rice in rotation with cowpea for green manure (GM), and (4) rice in rotation with "improved" grass-legume pasture leys. Cowpea or GM rotations occurred within each year, i.e., rice was sown in the first season (semester) and the legumes in the second season annually. Pastures were sown simultaneously under rice in 1993 and again in 1998, and grazed for 4 years. The same rotations were implemented with maize except that the legume used was soybeans. Native savanna plots were maintained for baseline comparisons. Rice plots received an annual application of 200 kg $ha^{-1}$of dolomitic limestone, 80 kg-N ha^{-1} (split: 20+30+30), 60 kg-P ha^{-1} and 100 kg-K ha^{-1}. Legumes (cowpeas or GM) received 20 kg-N ha^{-1}, 40 kg-P ha^{-1} and 60 kg-K ha^{-1}. Pastures were fertilized every two years with 20 kg-P ha^{-1}. Plot sizes 200 m × 18 m (3600 m^2) were used to allow for grazing by cattle and the use of conventional machinery. Maize plots received an annual application of 200 kg ha^{-1} of dolomitic limestone, 120 kg-N ha^{-1} (split: 33+33+33%), 80 kg-P ha^{-1} and 100 kg-K ha^{-1} (split: 33+33+33%).

A satellite experiment was carried out at Matazul farm (4° 9' 4.9" N, 72° 38' 23" W and 260 masl). The area has and average annual rainfall of 2719 mm, mean temperature 26.2 °C, EPT of 1623 mm and RH of 81%. The soil is classified as Typic Haplustox Isohypertermic Kaolinitic. A complete randomized block experimental design in two textural soils (light and heavy) with three doses of dolomitic lime (1, 2 and 3

Mg ha^{-1}) were incorporated with chisel at different depths 0-15, 0-30 and 0-45 cm respectively, and with a disk harrow (control) at 0-10 cm depth. The objective of the experiment was to improve the physical conditions of the soil, to facilitate root penetration at different depths and to improve the chemical conditions through lime and fertilization. The amount of Ca, Mg and K was calculated to increase base saturation levels in the exchangeable complex at 50%, 20% and 5% respectively. The Amount of P applied was calculated to increase its content to 20 ppm. Two crops were sown; maize and *Panicum maximum*. Maize plots were sown each year for three consecutive years, while pasture was established only in the first year. After three years of chisel and harrowing treatments maize plots were sown with a direct-drilling machine, to study the residual effects of previous treatments. Chemical and physical characteristics of the soils are shown in Table 1.

1. Bulk density in Cerrado (Brazil) and Colombian Llanos (Savanna) soils

It has been accepted that savanna soils in the world and especially in South America are similar, because they exhibit almost the same landscape and vegetation. However, savanna soils of different places (South America and Africa) present different natural soil conditions for root growth and the responses to cultivation are also different. Figure 1 shows bulk density values of Brazilian Cerrados soils and of some soil series of Carimagua in the Colombia Llanos.

Clearly Cerrados soils exhibited lower bulk density values through the soil profile (0 to 200 cm depth) than the soils from Carimagua. Brazilian soils presented bulk density values of less than 1.0 Mg m^{-3} except when the soil was cultivated conventional tillage. Altillanura soils presented values from 1.25 to 1.7 Mg^{-3} in the 0 to 100 cm depth in edaphic terms this means that Brazilian soils have a better infiltration rate, water distribution, water storage capacity, capacity for root growth, soil volume for root exploration, pore soil continuity for water flux, etc. as compared with Altillanura soils, which are harder, with low infiltration capacity, less porosity, less volume for root development, etc. The main reason for these differences lays on the geological origin of both soils. Brazilians Cerrados have been development *''in situ''*, while Altillanura soils has been mostly formed by sediment deposition coming from the mountains. Rice systems are compared in relation to native savanna.

2. Impact of crop-livestock systems on soil physical conditions

Changes in soil physical properties as a result of crop rotations and ley farming systems are are shown in Table 2. The saturated hydraulic conductivity of this Oxisol under native savanna is low. A hydraulic conductivity of 10 cm h^{-1} would be considered critical for the prevailing climatic conditions at Carimagua (2700 mm year^{-1} and high intensity storms, sometimes 100-120 mm h^{-1}). Most of the observed values were below this critical value. These results indicate that this soil has limited ability for downward water movement, resulting in temporary waterlogging during intense storms. Movement of water through the soil profile is more critical with depth. Thus, soil management strategy to improve crop and pastures productivity must include practices to increase soil hydraulic conductivity.

Statistically significant differences for bulk density were found among systems at different depths but these values for 0-10 and 10-20 cm soil layers are considered non-limiting for root growth and distribution. Below the 20 cm soil depth where tillage implements (disc harrows) are not expected to have any direct impact, bulk density values were generally higher than those found in the ploughed layers. However, they were not substantially different than native savanna values found at the same depth, indicating that land preparation was not causing added compaction in subsoil layers.

Although some statistically significant differences in macroporosity were found among the different systems, values in the 0-10 and 10-20 cm soil layers are considered non-limiting for root growth and distribution. Below this depth, some values lower than the critical levels (10%) were observed. Rice monocropping resulted in marked decrease of macroporosity for 20-40 cm soil depth when compared with rotation systems.

Table 1. Some chemical and physical characteristics of the soils under study.

Variable	Light texture	Heavy texture
	Sandy loam	Clay loam
Chemical Characteristics		
pH	4.92	4.76
Calcium (cmol kg^{-1})	0.13	0.07
Magnesium (cmol kg^{-1})	0.06	0.06
Aluminium (cmol kg^{-1})	1.10	2.64
Phosphorus (mg kg^{-1})	2.80	2.60
Calcium saturation (%)	10.30	2.40
Magnesium saturation (%)	4.80	2.20
Aluminium saturation (%)	79.60	93.10
Physical characteristics		
Sand content (%)	60.0	30.0
Organic matter (%)	2.20	4.60
Infiltration (cm h^{-1})	1.87	1.37
Total porosity (%)	42.70	50.30
Penetrability (kg cm^2)	14.50	16.20
Soil strength (kPa)	60.20	63.70
Bulk density (Mg m^3)	1.49	1.27
Particle density (Mg m^3)	2.60	2.62

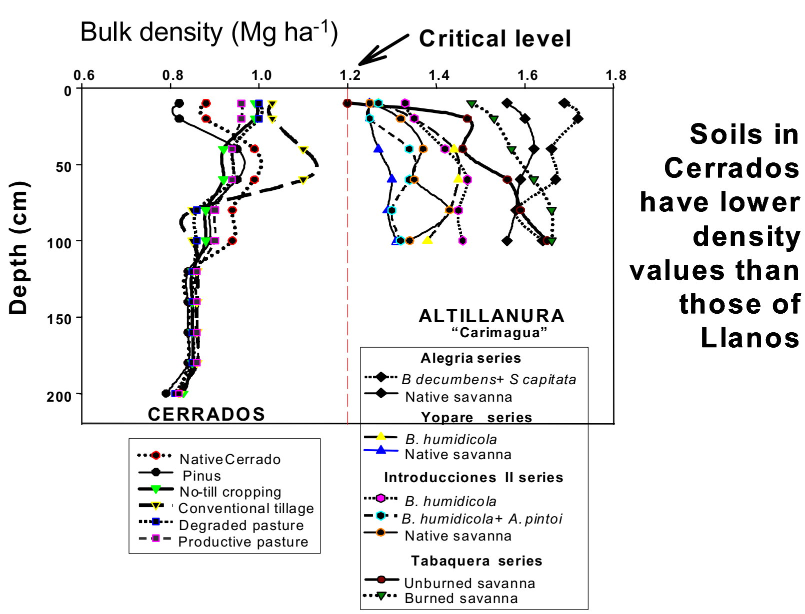

Figure 1. Bulk density (Mg m^{-3}) differences between Cerrados (Brasil) and Altillanura (Colombia) soils.

Table 2. Impact of different crop rotation and lay farming systems on certain soil physical characteristics at 5 years after establishment of the experiment.

Depth (cm)	Treatments	Hydraulic conductivity (cm h^{-1})	Bulk density (g cm^{-3})	Macroporosity (%)
0-10	Native savanna	5.1	1.24	14.6
	Rice-Agropastoral	3.9	1.31	12.3
	Rice-monoculture	5.3	1.17	19.6
	Rice-cowpea	7.4	1.29	14.6
	Rice-Cowpea green manure (GM)	6.1	1.19	14.4
	$LSD_{0.05}$	NS	0.09	5.1
10-20	Native savanna	0.9	1.31	11.3
	Rice-Agropastoral	0.5	1.37	7.8
	Rice-monoculture	5.9	1.23	15.9
	Rice-cowpea	14.4	1.23	17.1
	Rice- Cowpea green manure (GM)	13.5	1.25	17.2
	$LSD_{0.05}$	11.4	0.09	5.3
20-40	Native savanna	0.4	1.42	7.2
	Rice-Agropastoral	3.0	1.35	11.0
	Rice-monoculture	0.8	1.47	6.5
	Rice-cowpea	1.9	1.34	11.3
	Rice- Cowpea green manure (GM)	3.7	1.31	12.4
	$LSD_{0.05}$	NS	0.12	5.2

3. Impact of crop-livestock systems on soil chemical conditions

Temporal changes in soil pH and exchangeable Aluminium (Al) in all rice treatments were found to be very similar. The temporal fluctuations in soil pH and exchangeable Al observed in all soil layers can probably be attributed to variability associated with factors such as burning and temporary anaerobic conditions due to high rainfall which directly impact on soil pH and, consequently, in soluble Al. Increasing Soil P and Ca values reflected increasing system intensity. In the absence of inputs no significant changes in available P or exchangeable Ca in savanna plots were observed during the five years of experimentation. Available P remained at low levels in all soil depths (0-10, 10-20 and 20-40 cm), and exchangeable Ca was higher in the surface soil (0-10 cm) than in subsoil layers. Under the rice-agropastoral system, available P and exchangeable Ca levels increased modestly with time as a response to the initial applications of lime and P to the pioneer rice crop and the small bi-annual maintenance applications to the pasture thereafter. The resultant levels of available P (about 10 mg kg^{-1}) are considered adequate for acid soil adapted forage germplasm.

Under rice-monocrop system, P availability increased during the first three years in response to P fertilization but remained unchanged in the latter two years, especially in the surface soil layer (0-10 cm). This could be due to P removal by weeds which became increasingly prevalent as the experiment progressed, and to P fixation by soil incorporated from subsoil layers through excessive ploughing. The increase in available P in the 10-20 cm layer in 1998 supports this interpretation. Exchangeable Ca increased in all soil layers as a response to annual lime applications. In the surface soil, the largest increase occurred in the first year and remained unchanged thereafter. Instead, annual Ca inputs were reflected in the 10-20 and 20-40 cm layers which progressively increased during the 5 year period, presumably due to leaching from the surface soil.

Changes in soil pH and exchangeable Al did not correlated well with changes in exchangeable Ca, probably due to the very low lime rates applied and the leaching of Ca moving downward as accompanying cation with nitrate or chloride anions which did not affect pH. Changes in exchangeable Ca under the rice-cowpea rotation were very similar to those under rice monoculture although movement of Ca into the subsoil was slightly less, perhaps due to scavenging by deep cowpea roots and cycling of Ca back to the surface through cowpea residues. In contrast, levels of available P in the 0-10 cm layer increased much more sharply over time and were accompanied by increased levels of available P in the subsurface 10-20 cm layer. These increases in available P reflect the additional applications of P fertilizer to cowpea component of the rotation while subsoil increases were probably that result of the increased frequency of cultivation required for the cowpea crop.

The rice-GM system was the most intensely cultivated. Although inputs of lime and P fertilizer were the same as for the rice-cowpea system, there were some notable differences in available P and exchangeable Ca dynamics between the two. Exchangeable Ca in the 0-10 cm layer did not rise to the levels observed in either the rice monoculture or the rice-cowpea system, although changes in the subsoil layers were very similar. This can be explained by an increased rate of leaching of soluble Ca through the soil profile with the much higher nitrate concentrations generated by mineralization of ammonia produced by decomposing GM residues. Available P followed a similar temporal trend to that observed in the rice-cowpea system in the first three years. However, in the latter two years, the increased intensity of tillage apparently caused some incorporation of P.

4. Relationship between maize productivity and root growth

Average maize yields after 5 years of the establishment of treatments for the maize planted after native savanna, maize monocrop and after pastures are shown in Figure 2. Yields ranged from 1.2 under native savanna to 4.2 Mg ha^{-1} after 5 years of pastures, showing the beneficial effect of pasture roots in maintaining a good soil physical, chemical and biological soil environment maize production. Monocrop maize yields after 5 year of continuous cultivation were of about 2.1 Mg ha^{-1}. Therefore, the use of the roots of pastures for improving soil conditions is essential for increasing and maintaining maize productivity (Figure 3).

A relationship between depth of maize roots and maize yields is shown in Figure 4 . The figure shows that as maize roots presence increased in depth, yields increased. Low yields (1 Mg ha^{-1}) were found when rooting depth was restricted to the 0-10 cm depth which occurred under the native savanna treatment. Higher yields occurred when roots were able to penetrate to 40 cm depth, which occurred in maize plots after 5 year of the *P. maximum* pasture. From this information we can conclude that a practical depth of soil preparation could be around 28 cm and this should be done with chisels. As rooting depth increases roots have a higher volume of soil to explore and, therefore more water and nutrients are available.

5. Matazul satellite experiment

To test the concept of building-up an arable layer two textural soils (light and heavy) were selected in Matazul farm to establish the experiment. Some physical and chemical conditions of these soils are shown in Table 3.

The main objective was to improve the productivity capacity of these soils to a depth of 45 cm. In a first step the soils were loosened with chisel to a depth 0-15 and 0-30 cm afterwards in the second land preparation they were loosened to 30 and 45 cm depth respectively. Lime was calculated to reach a final calcium saturation of 50% at depths of tillage and was incorporated with chisels (vertical land preparation); Mg and K were applied to reach saturation values of 20% and 5% using appropriated sources of fertilizer (Dolomitic lime + sulcamag and KCl). The following scheme was followed (Figure 5).

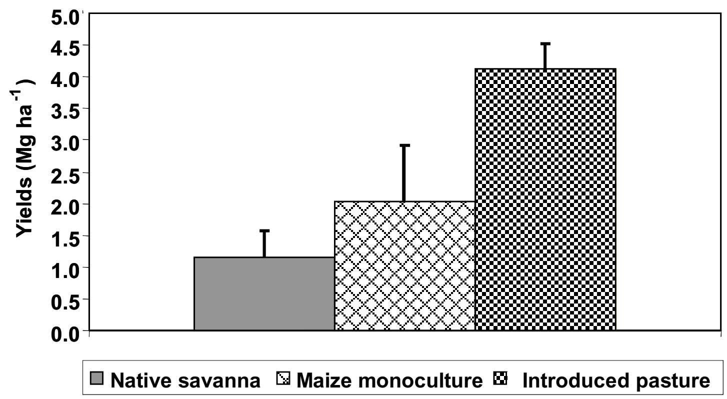

Figure 2. Maize yields under three different systems (culticore).

Figure 3. Roots of maize under minimum-till after 5 years of crop-pasture rotation.

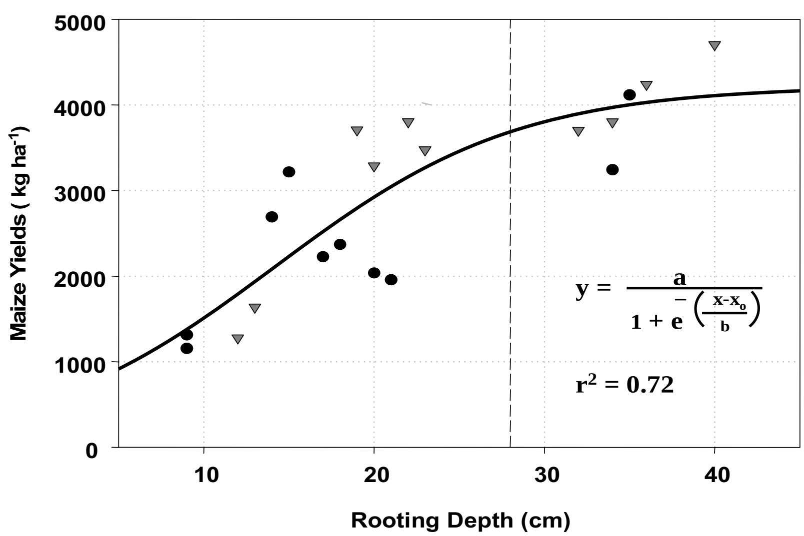

Figure 4. Relationship between maize yields and rooting depth in Culticore.

Table 3. Some physical and chemical conditions.

Variable	Light texture	Heavy texture
	Sandy loam	**Clay loam**
Chemical Characteristics		
pH	4.92	4.76
Calcium (cmol kg^{-1})	0.13	0.07
Magnesium (cmol kg^{-1})	0.06	0.06
Aluminium (cmol kg^{-1})	1.10	2.64
Phosphorus (mg kg^{-1})	2.80	2.60
Calcium saturation (%)	10.30	2.40
Magnesium saturation (%)	4.80	2.20
Aluminium saturation (%)	79.60	93.10
Iron (ppm)	19.10	12.60
Manganese (ppm)	1.20	1.10
Cupper (ppm)	0.20	0.50
Zinc (ppm)	0.40	0.40
Boron (ppm)	0.16	0.20
Physical characteristics		
Sand content (%)	60.00	30.00
Organic matter (%)	2.20	4.60
Infiltration (cm h^{-1})	1.87	1.37
Total porosity (%)	42.70	50.30
Penetrability (kg cm^2)	14.50	16.20
Soil strength (kPa)	60.20	63.70
Bulk density (Mg m^3)	1.49	1.27
Particle density (Mg m^3)	2.60	2.62

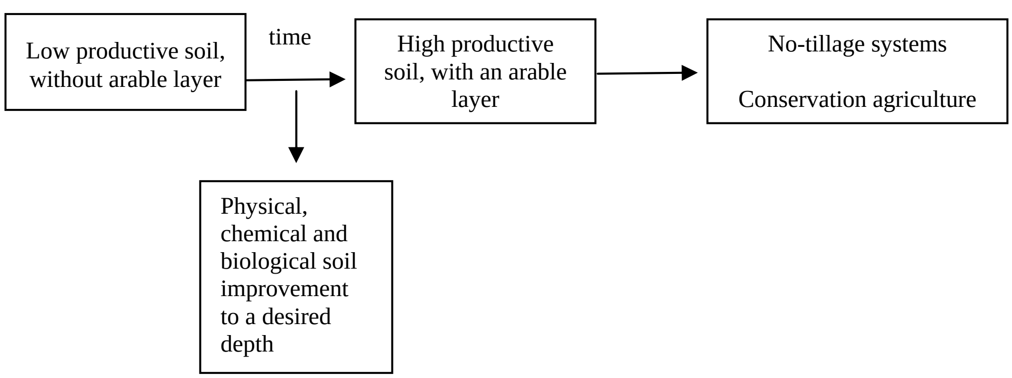

Figure 5. Strategy to convert low productive soil to high productive soil through buildup of arable layer.

After three years of the experiment some changes occurred (Table 4). As compared to native savanna, infiltration and total porosity increased. Infiltration rate passes from 1.87 to 8.1 and 3.4 cm h^{-1} in the light soil and from 1.37 to 2.90 and 9.20 cm h^{-1} in the heavy soil. However, in any of the cases the challenge goal (15 cm h^{-1}) was achieved. This means that it is needed to introduce more roots into the soil profile to increase infiltration capacity and to maintain a better soil bulk condition. By the other hand, it is clear that the heavy soil is responding more satisfactory to the treatments.

Total porosity also increased with treatments from 42.7% under native savanna to 51.7% and 48.2% in the light soil and from 50.3% to 57.2% in both treatments in the heavy soil. Therefore, improving this soil property, soil penetrability, soils strength and bulk density diminished with treatments in relation to native savanna, showing an improvement in these conditions; a better soil environment for root growth. The goals were reached.

The effect of the treatments in the improvement of the chemical conditions of the light soil is presented in Table 5. The amount of Ca and Mg increased strongly with depth in comparison to native savanna. Both nutrients reached deeper depths under the condition of chisel to 45 cm depth. At 0-5 cm depth, Ca saturation increased from 12.06% under native savanna to a range between 58-71% in the treatments, independently of the system. At 5-15 cm depth it increased from 9.35% to a range between 40% and 70% due to the treatments. At a depth of 15-25 cm, very small increases were found when the chisel depth was of 30 cm, but higher when chisel depth was 45 cm depth. As the goal of the experiment was to increase Ca saturation to 50% at the depth of chisel, it can be seen that it was possible to surpass this goal at the first two depths, but it was behind this goal at deeper depths. Better Ca saturation in depth was found at a chisel depth of 45 cm. This is due to the fact that lime incorporation with chisel is not horizontally uniform. More uniformity is expected to be reached with successive incorporations over time.

The amount of P increased from 3.67 to 10.4 ppm in the top 0-5 cm layer and from 2.37 to 28.7 ppm at the second depth. Less increment was found at deeper layers, but P content was higher than the original in native savanna. The presence of more P in the second layer is due to chisel incorporation. P levels seemed to be adequate for crop growth in both soils.

Table 4. Soil physical improvement (0-15 cm depth) after 3 years of treatments.

Variable	**Native Savanna**	**Soil improvement**		**Goal**
		Chisel (0-30 cm)	**Chisel (0-45 cm)**	
Light soil				
Infiltration (cm h^{-1})	1.87	8.10	3.40	15
Total porosity (%)	42.7	51.70	48.20	50
Penetrability (kg cm^2)	14.5	3.16	3.00	<10
Soil strengh (Kpa)	60.2	19.30	21.50	<40
Bulk density (Mg m^3)	1.49	1.26	1.35	1.3
Heavy soil				
Infiltration (cm h^{-1})	1.37	3.90	9.20	10
Total porosity (%)	50.3	57.20	57.20	50
Penetrability (kg cm^2)	16.2	5.96	4.62	<15
Soil strengh (Kpa)	63.7	29.20	22.20	<45
Bulk density (Mg m^3)	1.27	1.10	1.10	1.0

Table 5. Effect of treatment in the improvement of the chemical conditions of the soil (arable layer) after 3 years. Light soil.

Soil depth (cm)	Native Savanna	Depth of chisel (0-30 cm)			Depth of chisel (0-45 cm)		
		Crop System			Crop System		
		1	2	3	1	2	3
Ca (cmol kg^{-1})							
0 a 5	0.170	0.91 b	1.14 a	1.21 a	1.64 a	1.64 a	1.69 a
5 a 15	0.113	0.57 a	0.59 a	0.67 a	1.04 a	1.06 a	1.03 a
15 a 25	0.077	0.10 b	0.16 a	0.17 a	0.23 a	0.28 a	0.21 a
25 a 35	0.070	0.08 a	0.09 a	0.10 a	0.11 a	0.14 a	0.13 a
Mg (cmol kg^{-1})							
0 a 5	0.100	0.37 a	0.40 a	0.41 a	0.49 a	0.44 a	0.48 a
5 a 15	0.047	0.40 a	0.33 a	0.34 a	0.46 a	0.50 a	0.45 a
15 a 25	0.033	0.05 b	0.07 b	0.09 a	0.11 a	0.14 a	0.11 a
25 a 35	0.027	0.03 b	0.04 ab	0.05 a	0.05 a	0.07 a	0.06 a
Ca-s at (%)							
0 a 5	12.06	58.0 b	61.6 ab	64.4 a	69.1 a	70.3 a	71.6 a
5 a 15	9.35	40.6 a	37.8 a	45.3 a	57.2 a	60.6 a	59.3 a
15 a 25	7.19	9.8 b	12.6 ab	14.3 a	19.2 ab	23.3 a	16.7 b
25 a 35	8.42	8.2 a	8.1 a	9.8 a	10.7 a	13.4 a	10.7 a
P (ppm)							
0 a 5	3.67	8.4 a	8.5 a	8.7 a	10.2 a	10.4 a	10.3 a
5 a 15	2.37	19.9 a	20.0 a	20.1 a	28.5 a	28.7 a	28.6 a
15 a 25	1.43	6.6 a	6.9 a	9.0 a	11.3 a	12.5 a	4.6 b
25 a 35	1.35	1.9 a	2.2 a	1.7 a	1.6 a	2.4 a	2.0 a

a, b) Same letters mean no significant differences at 5% level
System 1= Year 1 (Rice/Rice) + Year 2 (Maize/Pearl Millet + legume) + Year 3 (Maize)
System 2= Year 1 (Rice/Pasture) + Year 2 (Maize/Soybean) + Year 3 (Maize)
System 3= Year 1 (Rice+Pasture+legume) + Year 2 (Maize/Pearl Millet+legume) + Year 3 (Maize)

The effect of the treatments on the chemical characteristics of the heavy soil, are presented in Table 6. Ca and Mg content increased strongly with depth it both chisel depths, in relation to native savanna. Ca saturation reached values higher than 50% in the first layer, but lower with depth, showing that in this kind of soil, is more difficult to get uniform lime incorporation. But even so, Ca and Mg were not limiting for maize production. P content increased a little under the treatments in relation to native savanna. As well as in the light soil, higher values were found in the second layer, due to the chisel effects.

6. Maize yields

Although there was no much difference in yields between treatments, crops yields overall were higher than those in the traditional farmers harrow system (1000 in light and -1500 kg ha^{-1} in heavy soil, Table 7). In all three management systems (cropping system, source of lime and depth of chisel) there was an increase in maize yields as a function of time in both soils. Higher yields were obtained in the heavy than in the light soil (Table 8).

Table 6. Effect of tillage treatment in the improvement of the chemical conditions of the soil (arable layer) after 3 years. Heavy soil.

Soil depth (cm)	Native Savanna	Depth of chisel (0-30 cm)			Depth of chisel (0-45 cm)		
		Crop System			Crop System		
		1	2	3	1	2	3
Ca (cmol kg-1)							
0 a 5	0.090	2.85 a	2.02 b	2.18 b	2.90 b	2.90 b	3.31 a
5 a 15	0.057	0.86 b	0.79 b	1.06 a	1.00 a	1.26 a	1.27 a
15 a 25	0.050	0.17 a	0.17 a	0.18 a	0.22 a	0.23 a	0.26 a
25 a 35	0.043	0.10 b	0.17 a	0.09 b	0.12 a	0.15 a	0.22 a
Mg (cmol kg-1)							
0 a 5	0.077	1.02 a	0.84 ab	0.82 b	1.09 b	1.09 b	1.23 a
5 a 15	0.053	0.46 b	0.39 c	0.60 a	0.47 b	0.58 ab	0.66 a
15 a 25	0.043	0.09 b	0.08 b	0.11 a	0.12 a	0.14 a	0.12 a
25 a 35	0.043	0.05 b	0.06 a	0.04 b	0.06 a	0.06 a	0.12 a
Ca-sat (%)							
0 a 5	3.03	60.9 a	53.0 a	55.2 a	64.0 b	66.5 a	66.8 a
5 a 15	2.08	25.0 b	24.8 b	31.5 a	33.7 b	47.0 a	39.3 ab
15 a 25	2.21	6.8 a	7.3 a	7.3 a	9.2 a	12.5 a	12.3 a
25 a 35	2.47	5.2 b	8.9 a	5.1 b	6.5 a	10.3 a	10.2 a
P (ppm)							
0 a 5	4.49	3.9 a	4.2 a	4.1 a	7.3 a	7.4 a	7.5 a
5 a 15	1.69	16.7 a	16.6 a	16.8 a	10.9 a	11.0 a	11.2 a
15 a 25	1.69	2.4 b	2.6 ab	6.9 a	3.8 a	4.3 a	3.8 a
25 a 35	1.35	1.5 a	1.1 b	1.4 ab	1.2 b	1.6 ab	2.4 a

a,b) Same letters mean not significant differences at 5% level
System 1= Year 1 (Rice/Rice) + Year 2 (Maize/Pearl Millet + legume) + Year 3 (Maize)
System 2= Year 1 (Rice/Pasture) + Year 2 (Maize/Soybean) + Year 3 (Maize)
System 3= Year 1 (Rice+Pasture+legume) + Year 2 (Maize/Pearl Millet+legume)+Year 3 (Maize)

In the light soil maize yields increased on average from 3789 kg ha^{-1} in 2002 to 5375 kg ha^{-1} in 2003, showing an increase of yields as function of soil improvement over time and the use of superior genetic material. We started with open pollinated varieties and finished with hybrids of maize.

In the heavy soil, average maize yields in 2002 were 4306 kg ha^{-1} and 6196 kg ha^{-1} in 2003. Similar to the light soil, yields increased over time, due to the same factor plus the influence of higher clay content on soil fertility and water retention. These results suggest that the improvement of the physical and chemical conditions of these soils leads to better root growth, which is essential for high productivity and sustainability. Thus, the building up of an arable layer is a key concept and aslo a management tool to give roots the opportunity to explore a greater volume of soil. This concept can be applied to other soils with similar physical and chemical restrictions as in the soils of the Llanos.

Table 7. Maize yields (kg ha^{-1}) overtime in the light soil.

Treatment	**Maize yields (kg ha^{-1})**		
	Year 2002	**Year 2003**	
	Maize H-108	**Maize H-108**	**Maize commercial hybrid**
Crop System			
1	3285 b	4495 a	5237 a
2	4047 a	4484 a	5382 a
3	4034 a	4700 a	5454 a
Source of lime			
Dolomitic lime	3589 b	4573 a	5405 a
Sulcamag+lime	3988 a	4546 a	5371 a
Depth of chisel			
0 a 30 cm	3554 b	4534 a	5146 a
0 a 45 cm	4023 a	4585 a	5630 a
Average			
Cumulative lime (kg ha^{-1})	3789 c	4560 b	5375 a
0 a 30 cm	1560	2260	
0 a 45 cm	3000	4300	

a,b) Same letters mean not significant differences at 5% level
System 1 = Year 1 (Rice/Rice) + Year 2 (Maize/Pearl Millet + legume) + Year 3 (Maize)
System 2 = Year 1 (Rice/Pasture) + Year 2 (Maize/Soybean) + Year 3 (Maize)
System 3 = Year 1 (Rice+Pasture+legume) + Year 2 (Maize/Pearl Millet+legume) +Year 3 (Maize)

Table 8. Maize yields (kg ha^{-1}) overtime in heavy soil.

Treatment	**Maize yields (kg ha^{-1})**		
	Year 2002	**Year 2003**	
	Maize H-108	**Maize H-108**	**Maize commercial hybrid**
Crop System			
1	4016 b	4750 a	6093 a
2	4427 a	4777 a	6336 a
3	4474 a	4585 a	6158 a
Source of lime			
Dolomitic lime	4182 b	4581 a	6152 a
Sulcamag+lime	4429 a	4827 a	6240 a
Depth of chisel			
0 a 30 cm	4208 b	4602 a	6116 a
0 a 45 cm	4403 a	4800 a	6279 a
Average	`		
Cumulative lime (kg ha^{-1})	4306 c	4703 b	6196 a
0 a 30 cm	3640	3640	
0 a 45 cm	6240	6240	

a,b) Same letters mean not significant differences at 5% level
System 1= Year 1 (Rice/Rice) + Year 2 (Maize/Pearl Millet + legume) + Year 3 (Maize)
System 2= Year 1 (Rice/Pasture) + Year 2 (Maize/Soybean) + Year 3 (Maize)
System 3= Year 1 (Rice+Pasture+legume) + Year 2 (Maize/Pearl Millet+legume)+Year 3 (Maize)

The main conclusions from this study were:

1. Inherent bulk density and porosity of soils in the Cerrados are not as limiting for agricultural productivity as in Colombian savannas soils.
2. Results from the Carimagua experiment (Culticore) showed that there is a need for a physical, chemical and biological improvement of these soils before they can be managed under no-tillage systems
3. Maize yields after 5 years of *Panicum maximum* were higher, than after 5 years of maize monocropping system, demonstrating the importance of pasture roots in improving soil conditions for crop production.
4. Maize yields in the Carimagua experiment were highly correlated to rooting depth.
5. The concept of building up an arable layer in Matazul farm, to improve the physical, chemical and biological conditions of the soil, through vertical tillage and the use of soil amendments, showed a very positive impact on maize yields.
6. Maize yields increased with time; therefore, there was a permanent improvement of soil conditions for crop production.
7. The concept of building-up an arable layer should be applied in tropical soils with physical, chemical and biological constraints as those of the Colombian savannas soils, if the objective is to increase productivity and to reach sustainability, to cope with human demands.

Is biological nitrification inhibition (BNI) a widespread phenomenon?

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Nitrification, a microbial process, is a key component and integral part of the soil-nitrogen (N) cycle determining how N is absorbed, utilized or dispersed into the environment, all of which have large implications as to plant productivity and environmental quality. During nitrification, the relatively immobile NH_4^+ is converted to the highly mobile NO_3^-. This process strongly influences N utilization by plants, because the NO_3^- formed, is in many situations highly susceptible to loss from the root zone by leaching and/or denitrification. The loss of N from the root zone can also have large economic implications, valued at a US $ 15 billion annually fertilizer, along with environmental consequences such as nitrate pollution of ground water and eutrophication of surface waters. Management of nitrification by the application of chemicals is presently one of the few strategies available for improving N recovery, agronomic N-use efficiency (NUE) and limiting environmental pollution in some crops.

Suppression of soil nitrification has been observed to occur naturally in some ecosystems, termed biological nitrification inhibition (BNI) indicating that the inhibition originated from the plants in the ecosystem. The conservation of N and the resulting improved N status through BNI (this type of nitrification inhibition) is hypothesized as the driving force for the development of low-NO_3^- ecosystems. Some recent studies suggest that certain grass populations are able to influence nitrification in soil. Several researchers based on empirical studies also indicated that some tropical pasture grasses possibly inhibit nitrification. However, the concept remained largely unsupported because it was not feasible to conclusively demonstrate *in situ* inhibition of nitrification by chemicals released in the plant-soil system, due to lack of an appropriate methodology.

Recently, an assay using recombinant luminescent *Nitrosomonas europaea* has been developed at JIRCAS, Japan that can detect and quantify nitrification inhibitors released in the root zone. The present investigation was aimed at quantifying the inter- and intra-specific variability in BNI from various plant species, including pastures and field crops. This study focused primarily on BNI in tropical forage grasses, in particular *Brachiaria* species, considered to be well adapted to low-N environments of South American Savannas. A number of field crops were also included in the study to determine the likelihood of the widespread occurrence of BNI, as published information is not available in relation to the distribution of BNI ability.

The capacity to inhibit nitrification through the release of BNI activity from roots appears to be widespread among tropical pasture grasses such as *Brachiaria* spp. Among tropical pasture grasses, *B. humidicola* and *B. decumbens* have the highest BNI activity released from their roots. Among the tested cereal and legume crops sorghum, pearl millet, and peanut showed some degree of BNI capacity. Substantial genotypic variability for BNI was found in *B. humidicola* germplasm. Several high- and low-BNI genotypes were identified. Soils collected from high-BNI types showed little or no nitrification. This is in contrast to the soils from low-BNI types, which showed average nitrification (i.e. most of N in the soil converted to NO_3^-). The BNI activity from high-BNI type when added to soils showed a stable long-term inhibitory effect on nitrification. The more BNI activity added to the soil the greater was the inhibitory effect on soil nitrification. The BNI activity from high-BNI types had a stronger inhibitory effect on the enzyme hydroxylamine oxidoreductase (HAO) pathway than on the enzyme ammonia monoxygenase (AMO) pathway of *Nitrosomonas*, whereas BNI activity from standard cultivar (which is a medium-BNI type) had similar inhibitory effects on both enzymatic pathways. Our results demonstrate that BNI may be widespread among plants with significant inter- and intra-specific variability. Thus, this genetically controlled BNI function could have the potential to be managed and/or introduced into pasture grasses/crops that do not exhibit the phenomenon *via* genetic improvement approaches that combine high productivity with the capacity to regulate soil nitrification.

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

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Ongoing collaborative research with JIRCAS, Japan, has shown that B.*humidicola* CIAT 679 (high biological nitrification inhibition [BNI] activity), B.*humidicola* CIAT 16888 (highest BNI activity) and Hybrid Mulato (intermediate NI activity) inhibits nitrification of ammonium and reduces the emission of nitrous oxide into the atmosphere. On the other hand, *P. maximum* CIAT 16028 does not have this property to inhibit nitrification. Given these findings with *B. humidícola* accessions, 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 43 accessions of *B. humidicola* regarding the BNI 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 shoot and root production in terms of biomass.

A sandy loam Oxisol from the Llanos (Matazul) of Colombia was used to grow the plants (1 kg of soil pot^{-1}) under greenhouse conditions. A basal level of nutrients were applied before planting (kg ha^{-1}): 40 N, 50 P, 66 Ca, 100 K, 20 S and micronutrients at 2 Zn, 2 Cu, 0.1 B and 0.1 Mo. A total of 44 accessions were used (accessions *P. maximum* CIAT 16028 and *B. humidicola* CIAT 679, 682, 6705, 6738, 16180, 16181, 16182, 16183, 16350, 16867, 16870, 16871, 16873, 16874, 16877, 16878, 16879, 16880, 16883, 16884, 16887, 16888, 16889, 16890, 16891, 26145, 26151, 26152, 26155, 26160, 26181, 26312, 26411, 26413, 26415, 26416, 26425, 26427, 26430, 26438, 26570, 26573, 26638). A control without plants was also included. The experiment was arranged as a completely randomized block design with four replications. Each pot contained 6 plants to increase root biomass. After sowing, plants were allowed to grow for 15 weeks and were cut to 10 cm height to simulate grazing effects under field conditions.

NH_4-N (nitrogen source was ammonium sulfate) was added in four applications: 40 kg N ha^{-1} added to the soil when filling the pots, 40 kg N at times 30, 60 and 90 days after planting. Four weeks later plants were harvested (at 16 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 roots was removed and the roots were rinsed with deionized water. Once clean, the roots were fully submersed in 1mM NH_4Cl for 1 hour to trigger further BNI active compound exudation. Then the roots were immersed in 500 mL deionized water during 24 hours. The root extract was subsampled and around 100 mL were sent to JIRCAS in liquid form and inside a Styrofoam container with ice packs to maintain them refrigerated for testing the BNI activity level. Another 100 mL was stored in the cold room as a backup until the BNI was measured and then was discarded. The final concentrate was tested for its nitrification inhibitory activity using a specific bioassay developed at JIRCAS. Harvested plants were separated into leaves, shoot and roots. Dry matter content and N status of leaves, shoot and root biomass was determined. At harvest time, soil samples were extracted with KCl and analyzed for nitrate and ammonium levels.

Results on dry matter partitioning among shoot and root biomass from the comparative evaluation of the 44 accessions are presented in Table 9. Significant differences were found in root biomass, stem biomass, leaf biomass and total biomass. The accessions CIAT 26425, 26438 and 26573 produced the highest values of total biomass while accessions CIAT 26427, 26312 and 16867 were lower than the rest of *B. humidicola* accessions. The accessions CIAT 26438 and CIAT 26425 produced the highest root biomass among the tested accessions. Values of root biomass of those accessions were more than eight fold greater than the value for the lowest in the group, the accession CIAT 26312.

Results from the bioassay indicated substantial level of genotypic differences in BNI activity in the root exudates of the accessions tested (Table 10). BNI activity is expressed as AT units; one AT unit is defined as the inhibitory activity caused by the addition of 0.22 σM 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. The tested *B. humidicola* accessions presented a range in BNI activity between 44.8 AT units pot^{-1} and 207 AT units pot^{-1}, while the *P. maximum* 16028 exhibited lowest NI activity (0.55 AT units pot^{-1}). The highest values were observed with the accessions CIAT 26573 and CIAT 16887. However, lower values of AT units pot^{-1} were observed with the accessions CIAT 26312, CIAT 16890, CIAT 16884, CIAT 26413, CIAT 682, CIAT 16891 and CIAT 16880. No significant differences were found among the accessions CIAT 6705, CIAT 26430 and CIAT 16877 which showed intermediate level of BNI activity. The commercial cultivar, CIAT 679, which had been used in most of the previous work, presented similar values (66 AT units pot^{-1}) to the accessions CIAT 16883, CIAT 26155 and CIAT 16183.

Results on BNI 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 BNI activity could be exploited in a breeding program to select for genotypes with different levels of BNI activity. Accessions with superior BNI activity could be used as parents to regulate BNI activity in the genetic recombinants together with other desirable agronomic traits.

Correlation coefficients between plant (shoot and root) attributes and total or specific BNI activity indicated that root biomass is negatively associated with specific BNI activity (r^2 = -0.26) indicating that specific activity per unit root dry weight decreased with increase in root biomass. Total biomass (shoot + root) production also showed negative association with specific BNI activity (r^2 = -0.17). As expected specific BNI activity showed strong positive association (r^2 = 0.6) with total BNI activity.

Table 9. Dry matter partitioning differences among 43 accessions of *B. humidicola* grown in pots under greenhouse conditions. Plants were harvested at four months after planting.

CIAT Accession Number	**Dry matter (g pot^{-1})**			
	Root biomass	**Shoot biomass**	**Root / Shoot**	**Total biomass**
679	10.2 (3.26)	16.6 (2.36)	0.60 (0.13)	26.8 (5.50)
682	7.90 (2.25)	8.60 (1.05)	0.92 (0.24)	16.5 (2.83)
6705	4.73 (0.50)	9.32 (0.65)	0.51 (0.06)	14.0 (0.88)
6738	6.80 (0.97)	8.90 (0.76)	0.76 (0.05)	15.7 (1.71)
16180	7.30 (2.56)	6.94 (1.03)	1.11 (0.57)	14.3 (1.87)
16181	4.88 (1.40)	14.0 (2.04)	0.36 (0.13)	18.8 (2.07)
16182	5.33 (1.22)	9.51 (1.00)	0.57 (0.18)	14.8 (0.92)
16183	3.75 (2.70)	14.1 (4.60)	0.25 (0.13)	17.8 (6.99)
16350	3.96 (1.31)	9.99 (1.05)	0.40 (0.13)	13.9 (1.95)
16867	4.42 (0.29)	3.35 (0.47)	1.35 (0.23)	7.77 (0.46)
16870	7.42 (1.59)	6.60 (0.72)	1.12 (0.11)	14.0 (2.30)
16871	7.43 (2.95)	12.9 (1.54)	0.60 (0.33)	20.3 (1.78)
16873	4.85 (0.35)	10.7 (1.36)	0.46 (0.08)	15.6 (1.17)
16874	6.52 (1.64)	7.68 (1.30)	0.86 (0.24)	14.2 (2.44)
16877	8.77 (1.33)	6.55 (0.55)	1.34 (0.17)	15.3 (1.71)
16878	4.81 (0.59)	7.94 (1.51)	0.62 (0.11)	12.8 (1.89)
16879	6.85(0.88)	6.26 (1.04)	1.10 (0.11)	13.1 (1.85)
16880	6.10 (1.06)	5.77 (0.65)	1.05 (0.10)	11.9 (1.63)
16883	7.35 (1.00)	7.76 (0.70)	0.95 (0.10)	15.1 (1.52)
16884	9.36 (1.48)	9.33 (1.19)	1.00 (0.07)	18.7 (2.60)
16887	7.25 (0.34)	7.28 (0.50)	1.00 (0.05)	14.5 (0.79)
16888	7.31 (0.84)	5.90 (0.73)	1.26 (0.21)	13.2 (0.92)
16889	6.14 (1.22)	5.99 (1.58)	1.05 (0.23)	12.1 (2.48)
16890	5.75 (0.62)	6.12 (0.96)	0.95 (0.14)	11.9 (1.33)
16891	7.61 (0.47)	7.66 (1.15)	1.01 (0.18)	15.3 (1.31)
26145	5.59 (1.05)	7.23 (0.73)	0.78 (0.19)	12.8 (1.14)
26151	7.18 (1.17)	10.1 (1.11)	0.71 (0.05)	17.3(2.26)
26152	5.22 (0.43)	8.04 (0.48)	0.65 (0.08)	13.3 (0.41)
26155	5.25 (1.01)	16.0 (2.78)	0.33 (0.03)	21.2 (3.70)
26160	5.40 (0.54)	9.06 (0.99)	0.60 (0.12)	14.5 (0.76)
26181	6.40 (4.25)	19.9 (4.86)	0.35 (0.23)	26.3 (5.43)
26312	1.65 (1.58)	8.25 (0.97)	0.19 (0.17)	9.90 (2.48)
26411	4.74 (0.72)	8.27 (2.04)	0.60 (0.16)	13.0 (2.50)
26413	5.21 (1.17)	10.1 (2.10)	0.53 (0.17)	15.4 (2.50)
26415	9.63 (2.27)	17.2 (2.58)	0.56 (0.07)	26.8 (4.69)
26416	6.21(0.91)	8.09 (0.39)	0.77 (0.14)	14.3 (0.64)
26425	13.3 (5.76)	18.6 (9.99)	0.91 (0.51)	31.9 (6.30)
26427	4.28 (0.64)	5.87 (0.94)	0.74 (0.17)	10.2 (1.16)
26430	6.36 (0.82)	4.66 (1.06)	1.46 (0.55)	11.0 (0.52)
26438	14.6 (1.73)	16.3 (0.85)	0.89 (0.08)	30.8 (2.46)
26570	7.87 (2.42)	9.27 (1.46)	0.84 (0.13)	17.1 (3.83)
26573	12.2 (4.25)	17.8 (4.58)	0.75 (0.38)	30.1 (3.41)
26638	3.75 (2.25)	9.15 (5.45)	0.47 (0.17)	12.9 (7.59)
Panicum maximum CIAT 16028	11.5 (4.26)	15.6 (2.02)	0.75 (0.28)	27.1 (4.75)
LSD	**2.69**	**3.44**	**0.30**	**4.13**

Numbers in parenthesis indicate standard deviation. (LSD, $p<0.001$)

Table 10. Nitrification inhibitory activity (total BNI activity pot^{-1}) and specific activity (AT units g root dwt^{-1}) of the root exudates from 43 accessions of *B. humidicola* grown under glasshouse conditions. Plants were grown for four months before the collection of root exudates.

CIAT Accession Number	**BNI activity (in AT units pot^{-1})**	**Specific BNI activity (in AT units g root dwt^{-1})**
679	66.4 (0.48)	6.83 (0.05)
682	53.4 (16.0)	7.54 (3.85)
6705	151.0 (26.1)	32.0 (4.59)
6738	113.0 (25.7)	17.2 (5.23)
16180	71.4 (10.1)	10.4 (2.55)
16181	80.9 (0.57)	17.6 (0.12)
16182	105.0 (30.9)	20.1 (5.19)
16183	65.9 (0.27)	13.6 (0.06)
16350	107.0 (38.2)	29.7 (13.6)
16867	70.3 (6.50)	15.9 (1.16)
16870	80.6 (19.9)	11.1 (3.10)
16871	94.6 (0.26)	13.9 (0.04)
16873	112.0 (66.0)	23.5 (14.4)
16874	130.0 (84.1)	21.7 (15.0)
16877	151.0 (50.5)	16.9 (4.65)
16878	105.0 (33.3)	22.6 (9.89)
16879	70.4 (9.51)	10.4 (1.46)
16880	44.8 (14.1)	7.56 (2.90)
16883	68.3 (26.8)	9.32 (3.51)
16884	60.0 (31.2)	6.26 (2.88)
16887	195.0 (66.0)	27.1 (10.0)
16888	174.0 (33.9)	24.2 (6.17)
16889	136.0 (45.8)	21.8 (4.38)
16890	60.4 (17.6)	10.5 (2.66)
16891	60.0 (21.8)	6.74 (2.79)
26145	95.8 (29.0)	17.5 (5.78)
26151	124.0 (23.8)	17.9 (6.38)
26152	141.0 (35.9)	27.1 (6.52)
26155	67.9 (0.31)	13.0 (0.06)
26160	70.9 (38.0)	12.7 (5.75)
26181	93.5 (0.25)	20.6 (0.06)
26312	62.4 (0.63)	21.4 (0.21)
26411	118.0 (43.4)	24.6 (7.04)
26413	56.3 (19.8)	11.0 (3.55)
26415	93.3 (0.32)	9.26 (0.03)
26416	128.0 (24.4)	20.5 (1.74)
26425	71.6 (0.84)	6.42 (0.08)
26427	93.6 (40.3)	24.2 (11.5)
26430	151.0 (15.3)	24.1 (5.12)
26438	93.5 (0.07)	6.53 (0.01)
26570	168.0 (11.5)	22.6 (5.99)
26573	207.0 (3.21)	24.3 (0.38)
26638	93.0 (0.48)	19.9 (0.10)
Panicum maximum	0.55 (0.02)	0.07 (0.00)
LSD	**42.15**	**8.15**

Numbers in parenthesis indicate standard deviation. (LSD, $p<0.001$)

The presence of substantially higher levels of BNI activity in the root exudates of two CIAT accessions (26573 and 16887) draws attention to the need to study these accessions in more detail to understand the BNI phenomenon. As a continuation of this work, we have assembled a set of 23 accessions of *B. humidicola* to conduct a study to test the genetic diversity in BNI in a single experiment under similar growing conditions and analyses of BNI. The *B. humidicola* breeding program at CIAT has generated a hybrid population and this population will be useful to analyze the tradeoffs of BNI in terms of the relationships among productivity, forage quality and BNI activity.

Screening of 43 accessions of *B. humidicola* for specific and total biological nitrification inhibitory (BNI) activity resulted in quantifying genetic diversity in BNI and in identifying contrasting accessions with very high (CIAT 26573) and low BNI activity (CIAT 16880). Root biomass production showed negative association with specific BNI activity.

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

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[2]TSBF-CIAT, Colombia; [2]JIRCAS, Japan

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

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

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

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

So far four soybean crops have been harvested (March and August, 2005; February and July, 2006). In this report we present the data collected during the fourth cropping season, nitrification rate, nitrate accumulation in the soil (Ion exchange resins), the net fluxes of N_2O and nitrate and ammonium levels in the top soil (0–10 cm) after fertilizer application. Figure 6 shows the differences in total shoot biomass harvested during the fourth crop cycle (March – July 2006). The results between treatments presented significant differences (LSD, p<0.001). Total shoot biomass yields of *P. maximum* and the *B. humidicola* accessions were similar but greater than that of the biomass from cv. Mulato and soybean. The decreased vigor of cv. Mulato was found to be due to reduced N availability in soil. Soybean had a total shoot biomass markedly lower than that of *B. humidicola* 679 and *B. humidicola* 16888. The growth of the *B. humidicola* accessions had been stimulated with the ammonium sulfate application as N source.

Figure 7 shows total shoot biomass accumulated from the experimental plots. Total shoot yield of *P. maximum* and the cv. Mulato was significantly higher than that of soybean and the 2 accessions of *B. humidicola* (LSD, p<0.001).

Total N uptake by different species showed significant differences (LSD, p<0.001) (Figure 8). Soybean and *P. maximum* accumulated considerably more nitrogen than cv. Mulato and the 2 accessions of *B. humidicola*. The *B. humidicola* plots removed less N than what is being added as fertilizer.

The grain yield of soybean was similar to the first and second cropping seasons (1.4 Mg ha^{-1}) which was slightly lower than that of the commercial average in the region.

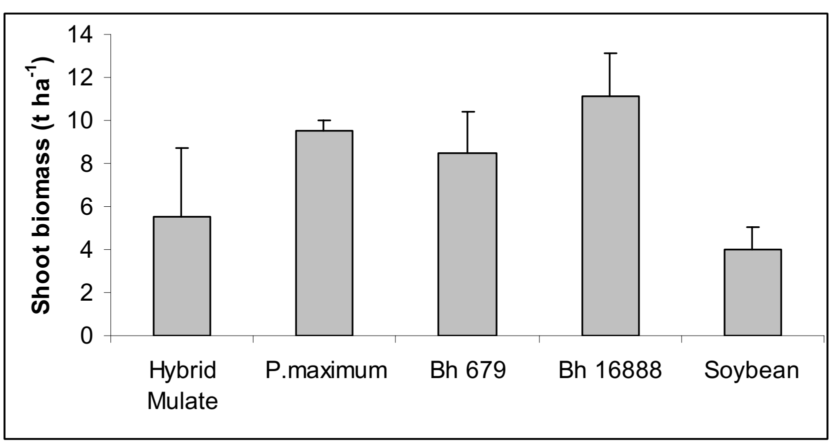

Figure 6. Shoot biomass production during the fourth cropping cycle (March – August 2005).

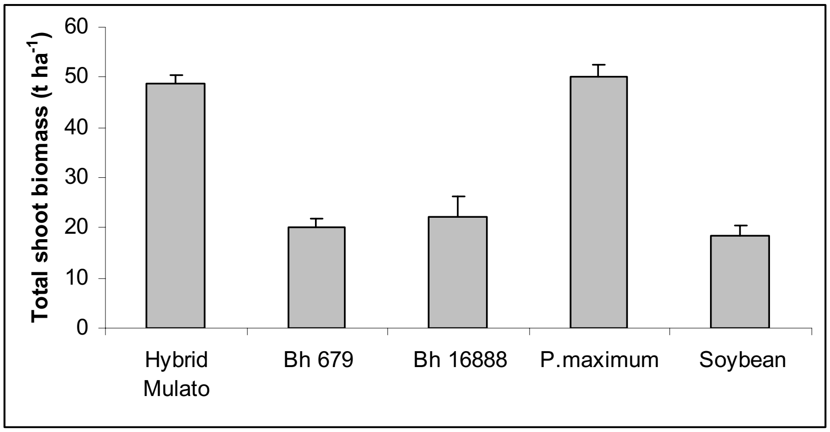

Figure 7. Total dry biomass production over the period of September 2004 and July 2006.

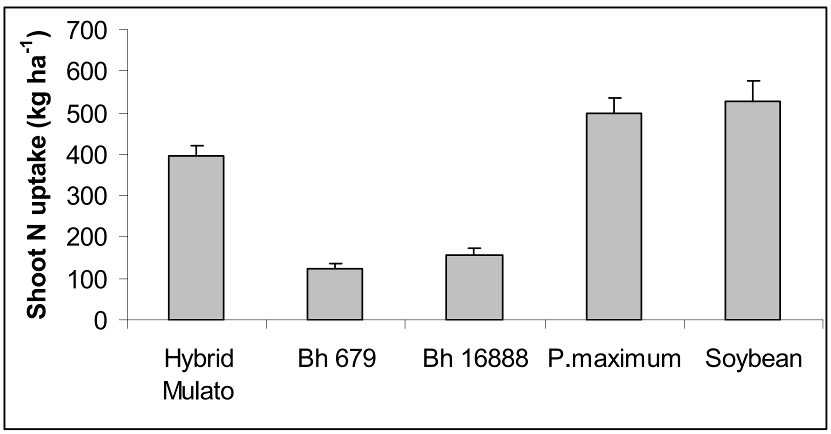

Figure 8. Total shoot nitrogen uptake for the period September 2004 and July 2006.

Soil ammonium and nitrate. Results on the nitrate levels in the top soil at harvest time showed significant differences (LSD, $p<0.001$) (Figure 9). The soybean plot showed higher levels of nitrate more likely as a result of lack of plant N uptake. The Bare soil and *P. maximum* also had high levels of soil nitrate, while the *B. humidicola* accesions clearly showed lower nitrate concentrations. The lower N uptake by two accessions of *B. humidicola* suggests a lower rate of nitrification with these two grasses or alternatively higher nitrogen losses. The ratio of NH_4/NO_3 in soil over time showed that *B. humidicola* 16888 had higher values after 20 days of fertilizer N application (Figure 10). Hybrid Mulato maintained the values over time compared with bare soil and *P. maximum*.

Nitrate accumulation in the soil (Ion exchange resins). Immediately after the second fertilizer application in June 2006, Ion exchange resins (Western AG, Canada) were inserted vertically in the soil to a depth of 10 cm. Four anion exchange units were randomly distributed in each experimental subplot. Resins were collected 7, 14 and 29 days after fertilize, adhered soil carefully removed with a brush and resins extracted with 1M KCl. Analysis of nitrate was done on the resin elution solution. Results on the amounts of nitrate adhered to the nitrate resins showed significant differences (LSD, $p<0.001$) (Figure 11). Seven days after fertilizer application, the soybean and bare soil plots showed higher levels of nitrate accumulated as a result of lack of plant N uptake. The *P. maximum* and Hybrid cv. Mulato also had high levels of nitrate accumulated in the ion exchange resins, while the *B. humidicola* accesions clearly showed lower nitrate concentrations. After fertilization and with the course of the days, the nitrate levels decreased gradually. Nevertheless, the accesions of *B. humidicola* showed lowest of NO_3-N at 7, 14 and 29 days after fertilizer.

With the purpose of establishing the time at which the maximum levels of nitrate, nitrite and nitrous oxide occur in soil, the soil was fertilized and a continuous sampling was made during 44 days. In Figure 12 we show that a day after fertilizer application, the maximum concentration of nitrate was observed. The average levels of nitrate were increased from 6.12 mg kg^{-1} NO_3-N (before fertilizer application) to 12.90 mg kg^{-1} (1 day after fertilizer application). It is important to emphasize that the 2 accessions of *B. humidicola* exhibited lowest values of nitrate in the top soil.

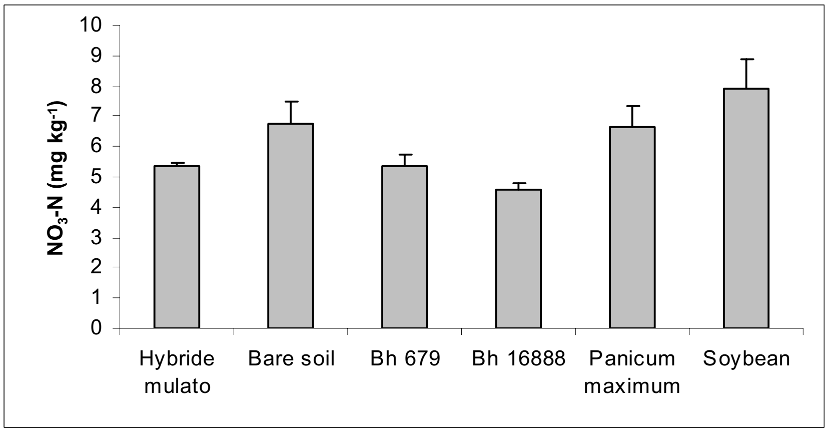

Figure 9. Nitrate levels in the top soil (0-10 cm) at harvest time of the fourth cropping cycle.

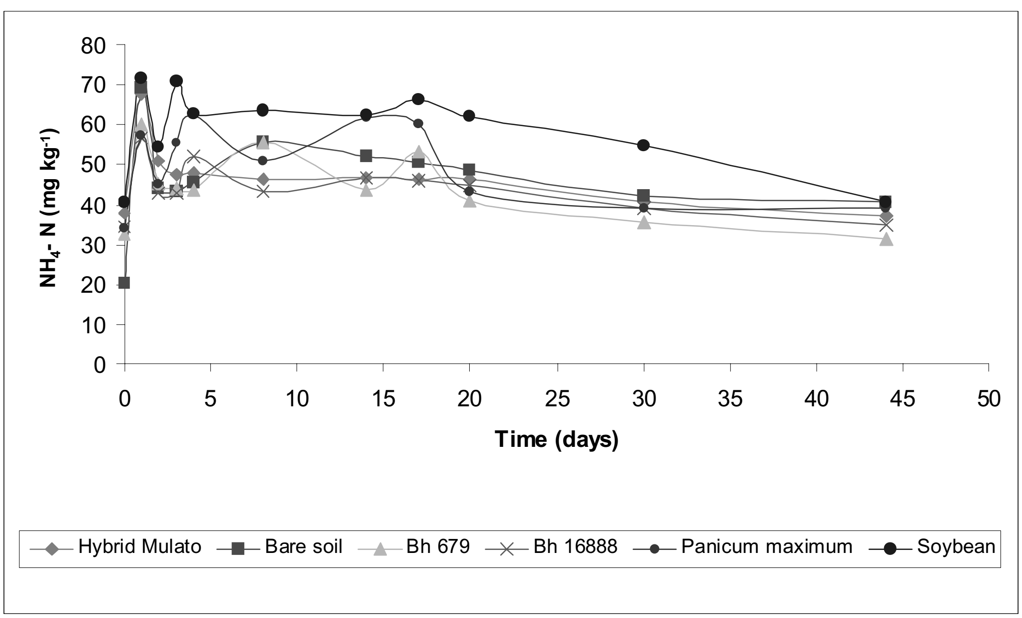

Figure 10. Ammonium to nitrate ratios in soil.

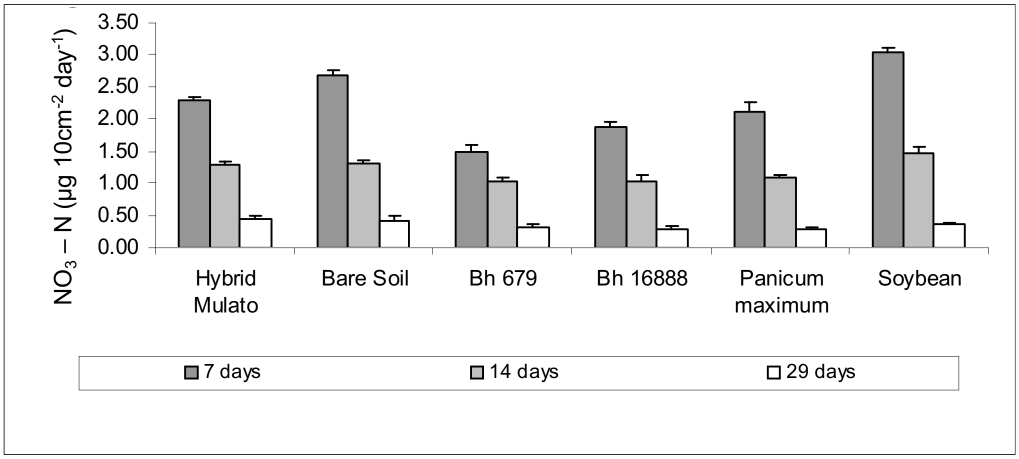

Figure 11. Nitrate retained in ion exchange resins over a 7, 14 and 29 days period after fertilizer application.

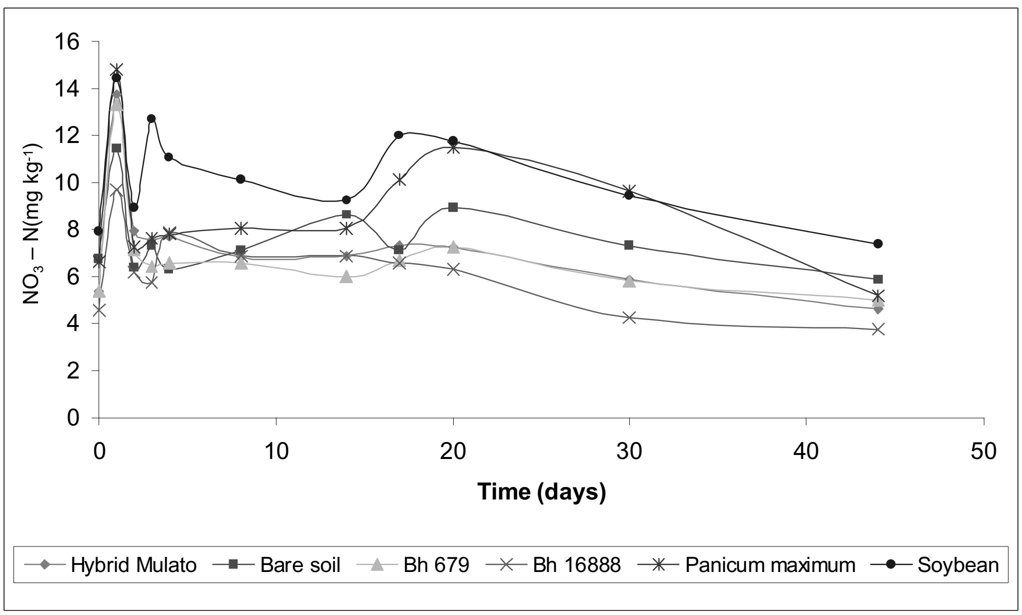

Figure 12. Nitrate levels in the top soil (0 – 10 cm) after fertilizer application.

Nitrous oxide emissions. Results on the behavior of the net fluxes of N_2O during 30 days after fertilizer application (March 31 – May 4, 2006) are shown in Figure 13. The highest concentrations were obtained at 1 and 3 days after fertilizer application while the lowest concentrations were observed at 20 days after fertilizer application. The fluxes were highest in the bare soil plots. These results support the view that *B. humidicola* is effectively inhibiting the nitrification process. However, *P. maximum* also showed lower net emissions of N_2O but this may be attributable to the much higher nitrogen uptake by the plants which may limit the total amounts of N available for nitrification, assuming that the grass is able to take up N from the soil in ammonium form.

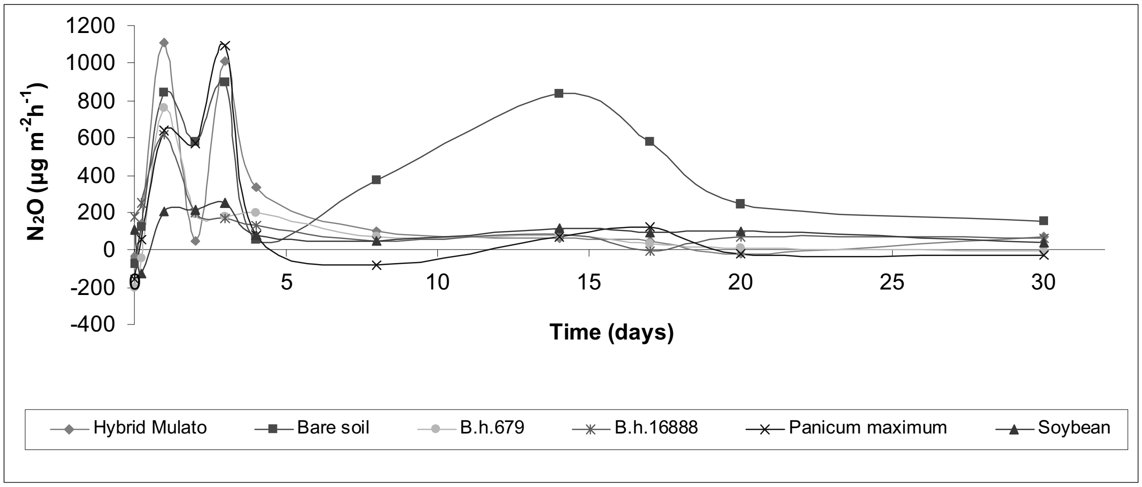

Figure 13. Net fluxes of N_2O during 30 days after fertilizer application.

Soil nitrification rates. Fresh rhizosphere soil was incubated to assess its mineralization rates during 30 days after fertilizer application. Soil samples were incubated with appropriate levels of ammonium and phosphate to favor nitrification. Chlorate was added to block the conversion of nitrite to nitrate and to measure rate of nitrite accumulation over time. Rate of nitrite accumulation was easier to measure than nitrate accumulation. Results presented in Figure 14 from the incubation test showed significant differences (LSD, $p<0.001$). Soybean showed stimulatory effect on nitrification while bare soil subplots presented the highest value of nitrification rate. *P. maximum* (no BNI activity) showed high levelof NO_2-N formation per day while cv. Mulato (intermediate BNI activity), *B. humidicola* 679 (high BNI activity) and *B. humidicola* 16888 (highest BNI activity) showed lower rates of nitrification.

Nitrate to nitrite ratio values in soil showed that the values were markedly higher with the bare soil treatment and were lower with the two *B. humidicola* accessions (Figure 15). These data also indicate greater inhibition nitrification by *B. humidicola* accessions.

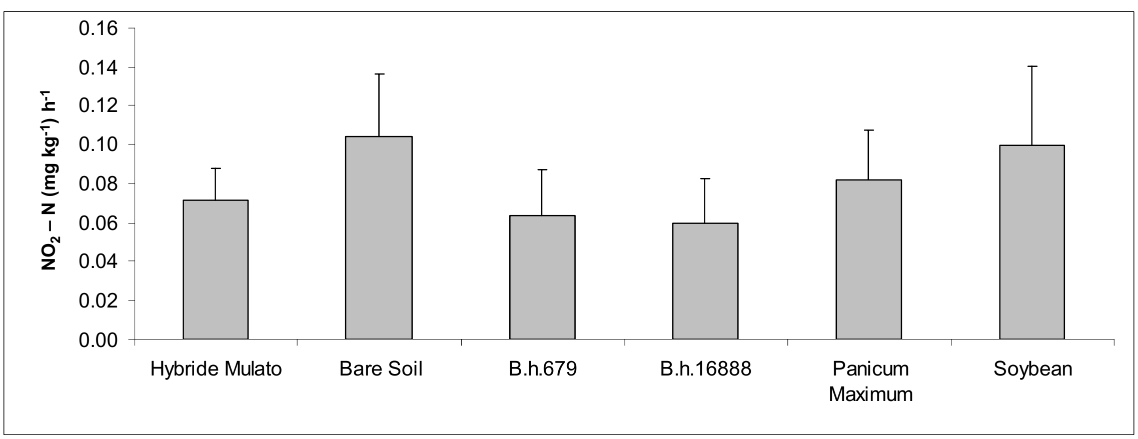

Figure 14. Average nitrification rates from incubated soils during 30 days after fertilizer application.

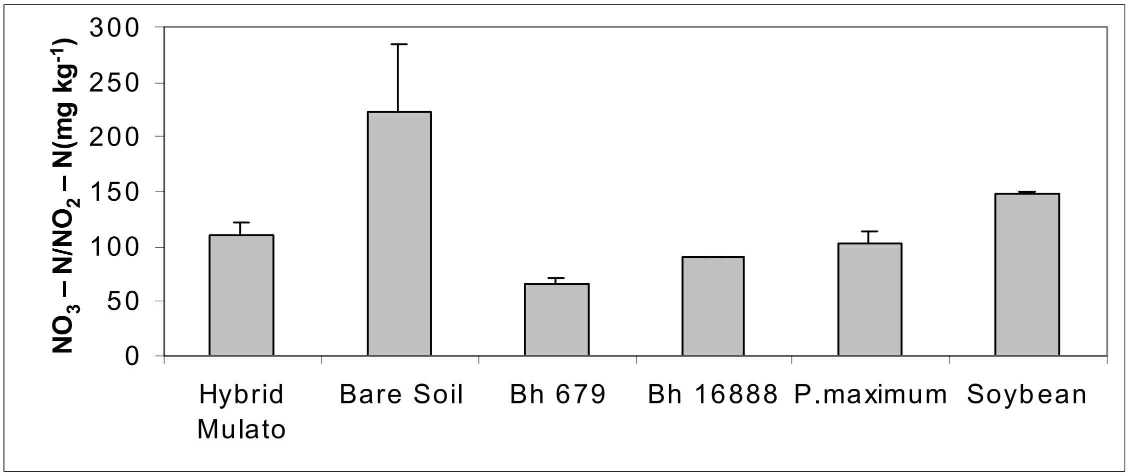

Figure 15. Nitrate to nitrite ratios in soil.

This field study after four cycles of analyses for BNI activity indicated that nitrification rates were lower with the two accessions of *B. humidicola* than the accession of *P. maximum*. The soil incubation method used for this study to estimate nitrification rates seem to be highly sensitive to detect even small differences in nitrification rates among the grasses. Further work is in progress to test the usefulness of this soil incubation method to quantify genotypic differences in BNI so that this method could be used as a screening method to quantify BNI among *Brachiaria* hybrids.

Soil microbial population analysis by Real-Time PCR to study Biological Nitrification Inhibition (BNI) activity of crops

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In soil, nitrogen (N) available to plants in the form of nitrate (NO_3^-) does not bind to soil particles due to its negative charge. Therefore, this form of N is highly susceptible to leaching and thereby it is lost from the system. Nearly 70% of the N fertilizer applied to agricultural soils is lost due to the nitrification process (oxidation of the relatively immobile ammonium - NH_4^+ - into the highly mobile nitrate - NO_3^- - N). In the same way, the loss of N from soil to the atmosphere in the form of other compounds, cause a negative impact on the environment by contributing to worldwide global warming and the greenhouse effect. Moreover, the soil N that is lost by leaching and/or denitrification can be substantial, which promotes pollution of ground water.

For these reasons, it is imperative to identify natural compounds that inhibit the nitrification process, which is carried out by soil nitrifying microorganisms including *Archaea*. In collaboration with JIRCAS of Japan, CIAT found that *Brachiaria humidicola* has the ability to suppress the activity of specific nitrifying microorganisms (bacteria and *Archaea*) by releasing inhibitory compounds from its roots to the soil. The inhibitory effect was mainly demonstrated by a bioluminescence assay using root exudates which will give indirect evidence for the phenomenon. To demonstrate direct evidence of the BNI phenomenon in soil, we report here the implementation and standardization of a Real-Time PCR technique to monitor microbial populations in soil, which allows us to study direct effects of roots exudates of several crops on the soil microorganisms involved in the nitrification process.

Soil samples used in this report were collected from the field study at CIAT-HQ (see Activity 3.4.3). The field has been used for BNI field work for three years, since 2004, and the work was partially supported by JIRCAS. The crops used in the field study were: soybean, *Panicum maximum,* Hybrid Mulato*, B.*

humidicola 679, *B. humidicola* 16888 and bare soil (as a control). The soil sampling was done at the end of the 4th growing cycle of soybean and before and one day after nitrogen fertilization of the 5th growing cycle. The soil samples were taken from a depth of 10 cm from a 1 m x 1 m sub-plot for every treatment using a metal tube with one side open. The two soil samples were mixed and the soil DNA extraction was performed using a FastDNA SPIN kit for Soil (Q-BIOgene, USA) according to the manufacturer's directions. Afterwards, the extracted DNA was quantified using the PicoGreen reagent and then was electrophoresed onto a 1% agarose gel to check its quality.

Four target genes (bacteria and *Archea amoA* genes and 16S rRNA genes) were amplified using specific primer sets: *amoA*-1F/*amoA*-2R, *amoA*19F/*amoA*643R, BACT1369F/PROK1541R, and Arch 20F/Arch 958R, respectively. These primers were demonstrated to be useful from published work. The *amoA* primers were designed to amplify t*amoA* genes, which encode a subunit of the ammonia-oxigenase enzyme that is presumably involved in the nitrification process in ammonia-oxidizing bacteria and *Archaea*. The other primers were used to amplify 16S rRNA gene, which was used as an internal control to track the population dynamics of the ammonia oxidizing bacteria and *Archaea* populations in soil.

To establish the PCR techniques for quantifing soil bacterial populations, we first generated standard curves to quantify the copy number of the target genes using gDNA from *Nitrosomonas europaea* for *amoA* gene and *Escherichia coli* for 16S rRNA gene, and plasmid DNA with the specific DNA inserts for *Archaea* amoA and 16S rRNA genes (figures 16 and 17). There were strong linear (R^2= 0.99) inverse relationships between Ct and the $\log_{10}$ number of amoA and 16s rRNA gene copies. This set a detection limit of gene copy numbers per DNA sample of interest in the reaction mixture.

In addition, the TaqMan technique was also carried out as a preliminary experiment to evaluate the viability of the technique to amplify the bacteria 16S rRNA gene using a specific probe and the primers mentioned earlier (data not shown). A universal Tm was used for all the primers to reduce variability among samples as much as possible, but the primer concentration was specific for each primer set. The TaqMan technique also proved to quantify accurately the bacteria 16S rRNA (data not shown) and therefore can be used for further studies.

Likewise, as we observed in Figure 18, the sharp fluorescence plot of the standard curve obtained from Real-Time PCR experiments will ensure an accurate quantification of the target genes. In addition, the fluorescence plot of the melting curve showed that specific PCR products are being obtained with the primers used, which gives more reliability to the experiment (Figure 19).

Our results suggest that the PCR technique developed is precise and reproducible for monitoring soil bacterial populations. For the soil samples, we have isolated good quality DNA from the soil samples that were described above. Currently, we are implementing this technique along with a detailed statistical analysis to monitor effects of BNI in the field conditions on bacterial populations of ammonium oxidizing bacteria and *Archaea*.

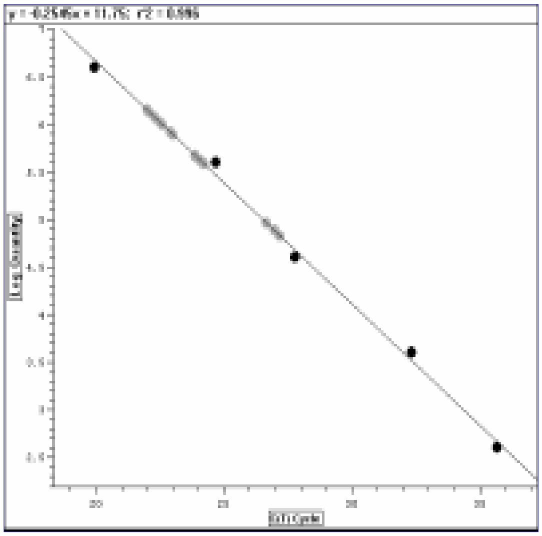

Figure 16. Standard curve generated from *E. coli* gDNA to quantify the copy number of the bacteria *amoA* gene.

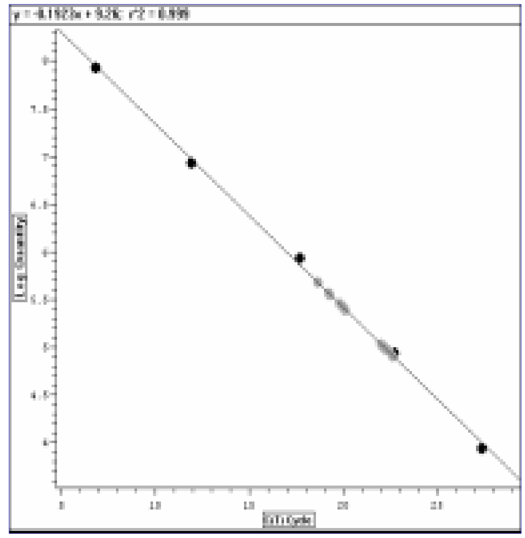

Figure 17. Standard curve generated from plasmid DNA to quantify the copy number of the *Archaea* 16S rRNA gene.

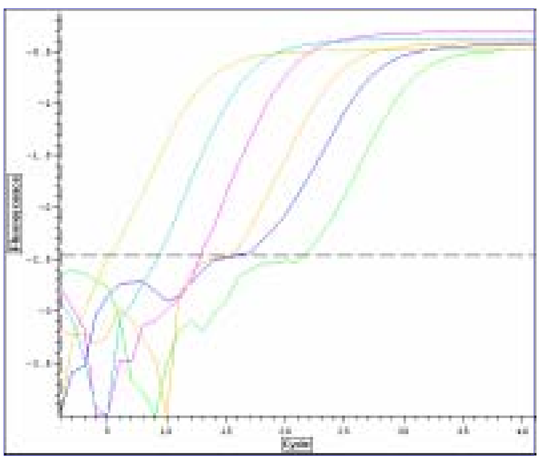

Figure 18. Fluorescence plot of PCR products of bacteria *amoA* gene using diluted *Nitrosomonas* genomic DNA

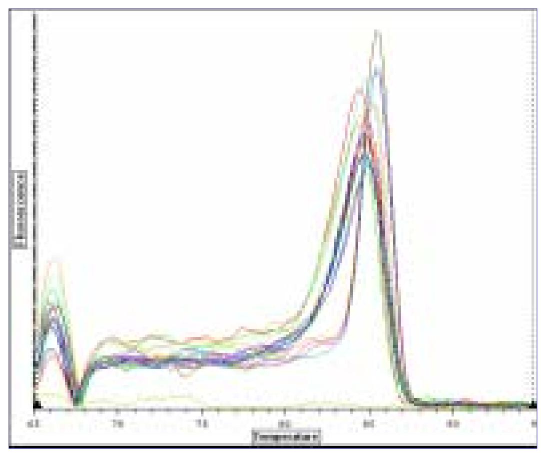

Figure 19. Melting curve of PCR products using a primer set for Archaea 16S rRNA gene. The DNA template used for this experiment was a diluted plasmid DNA containing Archaea 16S rRNA.

Output target 2007

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

Published work

Moreira, F.M.S., Siqueira, J.O. and Brussaard, L. (Eds) (2006) Soil biodiversity in Amazonian and other Brazilian ecosystems, CABI Publishing, Cambridge, UK, 280 p.

Abstract: The book reviews soil biodiversity in one the key biodiversity hotspots of the world, i.e. the Amazon and nearby regions of Brazil. It covers both the tropical savannah and the rainforest. The work presented is based on the Brazilian component of the project 'Conservation and Sustainable Management of Below-ground biodiversity', executed by TSBF-CIAT with co-financing from the Global Environment Facility (GEF) and implementation support from the United Nations Environment Programme (UNEP). The book presents a major contribution to the literature, to the interest of those involved with biodiversity conservation, soil science and ecology. In nine chapters, biodiversity of following nine functional groups of soil organisms is described: soil macrofauna, earthworms, termites, ground-dwelling ants, soil mesofauna, nematodes, microfungi, arbuscular mycorrhizal fungi and nitrogen fixing leguminosae-nodulating bacteria. Remaining chapters are for the description of soil and land use in the Amazon region and for discussing the key role of the Amazon in the quest for the conservation and sustainable use of biodiversity.

Constantino[1], R., Acioli[2], A.N.S., Schmidt[1], K., Cuezzo[3], C., Carvalho[1], S.H.C. and Vasconcelllos[4], A. (2006) A Taxonomic revision of the Neotropical termite genera *Labiotermes* Holmgren and *Paracornitermes* Emerson (Isoptera: Termitidae: Nasutitermitinae). Zootaxa 1340:1-44.

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Abstract: The taxonomy of the South American termite genus *Labiotermes* Holmgren (*sensu novo*) is drevised, including identification keys to soldiers and workers, and distribution maps for all 10 species. *Paracornitermes* Emerson is treated as a new synonym of *Labiotermes*. Two new species are described: *L. guasu*, from the Amazon rain forest and *L. oreadicus*, from the Cerrado of central Brazil. *Paracornitermes caapora* Bandeira & Cancello and *P. hirsutus* Araujo are placed under the synonymy of *L. orthocephalus*. The images of *L. emersion* and *L. orthocephalus* are described for the first time. The workers of all species are described and illustrated, including the enteric valve armature and the mixed segment. The soldiers of the species previously included in *Paracornitermes* are redescribed. The revision of these genera is based partly on data obtained from the inventory of termites in the Amamzonian benchmark area of the BGBD project. Together with evidence form studies conducted elsewhere in Brazil the revision is proposed.

Tondoh, Jérôme Ebagberin, Lazare Monin Monin, Seydou Tiho and Csaba Csuzdi (2006) Can earthworms be used as bio-indicator of land-use perturbations in semi-deciduous forest? Biology and Fertility of Soils, Springer Verlag.

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Abstract: The potential of tropical earthworms as bioindicators of forest degradation by human-induced activities was assessed at a landscape level in the Ivory Coast. The study site covered 400 ha and was characterized by a set of land-use types along a gradient of perturbation from semi-deciduous forest, through reforestation, fallow systems to cultivated annual crops. Samples were taken on a grid at each sampling point and earthworms were hand-sorted from a 25×25×30 cm soil monolith. Results showed a potential increase in relative populations (number: +53.1%, biomass: +94.8%) of species in the

earthworm communities following forest conversion. Furthermore, the impact of land-use change was higher in relation to land-use intensification in terms of earthworm populations and diversity in intermediate disturbed systems (Multispecies plantations, old fallows). Earthworm diversity was the most sensitive response to land-use change. The species *Dichogaster saliens* Beddard (1893), *Hyperiodrilus africanus* Beddard (1891), *Millsonia omodeoi* Sims (1986), *Dichogaster baeri* Sciacchitano (1952), *Dichogaster ehrhardti* Michaelsen (1898), *Agastrodrilus* sp., *Stuhlmannia palustris* Omodeo and Vaillaud (1967) and, to some extent, *Millsonia* sp. appeared to be most sensitive to land-use change. More field and laboratory investigations are needed to find out the most efficient species to be used

Completed work

Density and diversity of associative diazotrophic bacteria in soils under diverse land use systems in amazonia

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Associative diazotrophic bacteria are among the important functional groups of microorganisms that live in soils. These bacteria contribute to plant growth mainly through biological N_2 fixation. The aim of this work was to evaluate the density and diversity of associative diazotrophic bacteria *Azospirillum* spp., *Azospirillum amazonense* and *Herbaspirillum* spp., in soils under diverse land use systems (LUS) in Amazonia. Thirty soil samples at different LUS in Amazon region were collected in March, 2004: forest (6 points); young secondary forest (6 points); old secondary forest (1 point); crop (5 points); pasture (6 points) and agroforestry (6 points). The density was evaluated in August 2004, with serial decimal dilutions (10^{-2} to 10^{-8}) of soil samples to determine most probable numbers (MPN) in media: JNFb (*Herbaspirillum* spp); NFb (*Azospirillum* spp.); Fam and LGI (*Azospirillum amazonense*). Phenotypic diversity of isolates and strains were evaluated through cell morphology in optic microscope, cultural characteristics on potato and GNA media as well as protein profiles by polyacrylamide gel eletroforesis (SDS-PAGE), compared to type and reference strains of *Azospirillum, Herbaspirillum* and *Burkholderia* species. No grown in JNFb was observed. In NFb medium the MPN increase in the following order: forest ($2.1x10^2$ bacteria g^{-1} soil); pasture ($4.6x10^2$ bacteria g^{-1} soil); secondary forest ($8.0x10^2$ bacteria g^{-1} soil); crop ($18.2x10^2$ bacteria g^{-1} soil) and agroforestry ($22.4x10^2$ bacteria g^{-1} soil). In Fam medium the MPN increased in the order: agroforestry ($0.9x10^2$ bacteria g^{-1} soil); forest ($1.6x10^2$ bacteria g^{-1} soil); secondary forest ($1.9x10^2$ bacteria g^{-1} soil); crop ($3.7x10^2$ bacteria g^{-1} soil) and pasture ($11.2x10^2$ bacteria g^{-1} soil). In LGI medium MPN increased in the order: agroforestry ($1.3x10^2$ bacteria g^{-1} soil); crop ($2.7x10^2$ bacteria g^{-1} soil); secondary forest ($3.6x10^2$ bacteria g^{-1} soil); forest ($4.2x10^2$ bacteria g^{-1} soil) and pasture ($8.1x10^2$ bacteria g^{-1} soil). Higher numbers were obtained in NFb medium ($10.6x10^2$ bacteria g^{-1} soil), followed by LGI ($4.1x10^2$ bacteria g^{-1} soil) and Fam ($3.9x10^2$ bacteria g^{-1} soil). Twenty-two isolates were obtained. Cell diameters varied from 0.55 to 1.11 σm with rods or spirillum shapes. Twenty groups were obtained by cultural phenotypic characterization on potato medium (2 in forest, 2 in young second forest, 4 in crop, 4 in agroforestry and 9 in pasture) and GNA medium (2 in forest, 2 in young second forest, 4 in crop, 5 in agroforest and 9 in pasture). Protein profile through SDS-PAGE analysis showed diversity amongst isolates. The LUS affected the density of diazotrophic populations and these effects depend on the medium: soils under crop and agroforestry presented larger numbers in NFb medium; in Fam and LGI media pasture usually presented larger density. The LUS also affected the diversity of diazotrophics, soils under pasture presented larger number of cultural phenotypic characteristics. This is explained by the well known positive effect of grass rhizosphere on this group of organisms.

Final Technical Report of the Project on Conservation and Sustainable Management of Below-Ground Biodiversity in India.

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The research work carried out in the benchmark area, Koothy village of Somwarpet taluk is located in the Kodagu district of Karnataka. This bench mark area is situated very close to the Nilgiri Biosphere Reserve at the northern region and lies between 120 401 0311 N – 120 421 1911 N and 750 471 1011 E – 750 791 1411 E. The annul rainfall of the area ranges from 2000 mm to 3500 mm. Most of the rainfall is drawn from southwest monsoon during June-August period. The temperature begins to increase from March to April with a mean daily maximum of 28.6 °C and a mean daily minimum of 17.8 °C. The temperature on some days might be as high as 32 to 35 °C during April or May. The daily lowest temperature of around 9 °C is recorded during the month of January. Coffee and cardamom plantations cover major part of the study area. The natural forests are found in the periphery of the plantations, which are evergreen with varying levels of degradation. A few patches of *Acacia auriculiformis* plantations (monoculture) and grassy blanks are found adjacent to the forests. Rain-fed agriculture is practiced in the valleys with one paddy crop every year during the rainy season. Additionally, crops like chilly and short duration grain legumes are also grown in summer utilizing the residual moisture and sparse rainfall of northeast monsoon.

Land use / Land cover mapping

Satellite data (IRS-D-LISS III data of the year 2000, path 98 and row 64) was interpreted to prepare land use/land cover map of the study area at 1:50,000 scale. Hybrid classification approach was adopted. A mask was created for almost non-overlapping classes (*viz*., agriculture areas and vegetated areas) obtained from unsupervised classification (which algorithm??). The vegetated areas are further classified into forests, grasslands, coffee/cardamom plantations and forest tree plantations by supervised classification (*maximum likelihood* classification algorithm). The outputs obtained from unsupervised and supervised methods were merged to get the hybrid output. Classified output was draped over Digital Elevation Model, misclassified patches identified and necessary corrections were incorporated. Six land use–land cover types could be distinguished in the study area. They are natural forest, grasslands, acacia plantations, coffee plantations, cardamom plantations and paddy fields.

A 200 m grid was overlaid on the map and 60 intersection points were sampled for aboveground/belowground biodiversity studies. The sample points identified on the map were reached in the field using handheld *Garmin 12*, Geographical Positioning System. A total of 60 sample points were distributed in two windows of size 6.4 km^2 (4 x 1.6 km) and 0.8 km^2 (0.4 x 2 km) so as to cover all the above said land cover types. Fifty three sample points were distributed in the first large window and seven points in the second small window. Stratified sampling technique was adapted and two windows were selected, because the first large window that was selected did not have enough natural forests, grasslands and *Acacia* plantations. Hence, additional window in the study site was selected to cover the required land use types. The sample points were laid in the intersection point of the windows and were located in the ground using hand held *Garmin 12* GPS. These intersection points at which sampling could not be done due to the presence of a natural obstruction (presence of a tree, stone/water body etc.) were skipped and the next sampling was done in the next intersection point.

Population of different functional groups

The population of *Azotobacter* and P-solubilizing microorganisms was much higher in natural forests except for AM fungi in terms of infective propagules and legume root nodulating bacteria in the pre-monsoon season (Table 11). In grasslands the number of infective propogules of AM fungi, the population of legume root nodulating bacteria (LNB) and *Azatobacter* showed a similar trend as in natural forests, whereas no such variation was observed between two seasons for the other groups. In Acacia plantations, LNB were high in the pre-monsoon season than in the post monsoon season.

But *Azatobacter* & P-solubilizers showed a low degree of density, while the population of LNB and AM fungi were at very high levels. A similar trend in the population of studied microbial groups was observed in coffee and cardamom plantations and paddy fields as that of natural forests.

The density of population of *Azatobacter* is influenced both by the season as well as by the above ground diversity. The total diversity of trees, shrubs and herbs, which is maximum in natural forests has supported, highest population of *Azatobacter* colonies followed by cardamom and coffee plantations. The grasslands, Acacia plantations and paddy fields that exhibited a poor diversity in the aboveground vegetation has very low density of *Azotobacter*. The population of *Azotobacter* has remained at a high level during the premonsoon season compared to the post-monsoon season.

The population of P-solubilizing fungi and bacteria has shown to be in very low levels in all the ecosystems other than the natural forests. Only in natural forests, the influence of seasons is well established unlike in other ecosystems. In the study site area, the social forests, agricultural and fallow lands are not supportive of the establishment of this group and it requires further investigations to understand their ecology In case of arbuscular mycorrhizal (AM) fungi, the pattern of colonization has remained more or less the same in all the ecosystems except in paddy where the levels are very low and not much variation is observed with respect to seasons. The spore density was found to be higher during both the pre and post-monsoon seasons in grasslands and Acacia plantations and was less than 50% of the density observed in all the other ecosystems irrespective of the seasons. The infective propogules were also more in Acacia plantations and least in paddy ecosystems. The above ground diversity seems to have much influence on the population of AM fungi rather than the soil structure.

The effect of season is more pronounced on legume nodulating bacteria in Acacia and coffee plantations where their maximum density was observed in the pre-monsoon season while it was in the post-monsoon season, very low density of this group was observed in the natural forests. Their density could be associated with the above ground legume plants that could promote the symbiotic association. But, the correlation for this factor is non-significant.

Earthworms that form the major soil macro fauna were found to be of least importance in pre-monsoon season and the collection had a very few earthworms of species of *Pantoscolex corethrurus* and some immature stages of the genus *Drawida*. Because of this, data is not reported for the pre-monsoon season. However, in the post-monsoon season 17 species of earthworms were collected from different ecosystems. The maximum species diversity and highest density of earthworms were recorded in coffee plantations followed by natural forests. The earthworm activity, their density and diversity were independent of the micro floral distribution in the representative ecosystems included in the study. No correlations could be drawn between the two groups except for LNB. Similarly, maximum distribution of earthworms during this season was restricted to 0-10 cm followed by 10-20 cm depth and very few earthworms were collected at 20-30 cm depth.

The litter feeders and organisms inhabiting ‘O’ horizon were predominant in the postmonsoon than in the pre-monsoon season. As in case of earthworms, the highest density and maximum diversity of litter organisms were found in coffee plantations. The litter cover of the highly diversified above ground flora in coffee plantations seems to be the preferred habitat for earthworms and litter fauna. The post-monsoon season having a moisture level suitable for their activity showed maximum diversity and density of earthworms and litter fauna. The soil fauna other than the earthworms were higher in 0-10 cm depth and their density and diversity was higher in coffee plantations in the pre-monsoon season.

This was followed by cardamom plantations and natural forests. The population density and diversity of these invertebrates in paddy fields were on par with coffee plantations. Least populations of these organisms were found in grasslands and Acacia plantations.

The study suggests that the soil faunal structure changes with the seasons and soil invertebrates other than earthworms; especially different groups of arthropods with impervious cover and smaller body size were predominant in the dry season. The soft bodied earthworms without protective body cover and soft-bodied arthropods were predominant in the post-monsoon period. In general, the itinerary of soil community structure at the study site has provided scope to judiciously modify the community structure to suit to promote low input agriculture.

Correlation between physical and chemical characters and functional groups

The physical and chemical composition of the soil at the study site and the phosphatase activity in the soil samples as a biochemical parameter were considered to relate the different groups of organisms in the community to the existing edaphic factors (Table 12). It was found that AM fungi and *Azatobacter* in the pre-monsoon season showed significant positive correlation to organic carbon content of the soils whereas soil and litter invertebrates other than the earthworms showed a negative correlation to the organic carbon content whereas the population of earthworm was unaffected. The earthworms showed significant positive correlation to clay and silt content and negative correlation to the sand content that was not statistically significant.

The existing earthworm population is highly influenced by the soil structure. Similarly, the other invertebrates showed positive correlation to clay and silt content and significant negative correlation to sand content. P-solubilizers and *Azatobacter* exhibited a significant positive correlation to sand content and negative correlation to clay and silt content. The results clearly show that these two groups require well aerated soils with high level of organic carbon for their existence and activity. Unlike as in case of P-solubilizers, the bulk density also affected the colonization of *Azatobacter* and seasons seems to influence this relationship. Similarly, the influence of seasons on the response of invertebrates other than earthworms to bulk density is observed in this study. Legume nodulating bacteria are unaffected by the organic carbon content or the other soil physical properties other than the clay content that showed significant positive correlation in the pre- monsoon season and bulk density that showed significant negative correlation in the post-monsoon season.

The N levels in soils has significant positive influence on P-solubilizers, LNB and soil invertebrates other than earthworms in post-monsoon season and negative effect on *Azatobacter*. This is an indication to show that *Azatobacter* fails to establish itself in soils having high levels of inorganic N and thus the natural process of N-fixation is adversely affected. Just as *Azatobacter* is affected by high levels of N, P-solubilizers as well as *Azatobacter* are negatively affected by the total and available- P in the soil. Other than the highly positive response of LNB, the other microorganisms are unaffected by levels of K. The earthworms and other soil invertebrates have positive relationship with K levels in soils. As these organisms depend on highly degraded plant material, the K in the degraded matter at different levels of decomposition could be associated with this correlation.

From this correlation study, it is clear that the soil structure is responsible for the diversity and abundance of soil invertebrates and chemical properties for the abundance of important functional groups of microorganisms like N-fixers and P-solubilizers. The symbiotic groups like LNB are not directly affected by the edaphic factors.

Correlation between different functional groups

The inter-relationships of different functional groups are tested by using correlation matrix (Table 13). The results have shown that these relationships among different groups are significantly negatively or positively correlated depending on the seasons and in some cases no such relationship was observed. The establishment of AM fungi is negatively affected by P-solubilizers and LNB in the post-monsoon season and by litter invertebrates in the premonsoon season. The P-solubilizers, N-fixing *Azatobacter* and LNB exhibited a positive relationship. LNB have a highly significant association with earthworms. Earlier studies carried out in our laboratory have shown such a stimulatory effect on nodulation in cowpea seeds treated with the coelomic fluid of earthworms and grown in pots amended with vermincompost.

(Unpublished data). Thus, burrows of earthworms coated with their body fluid under field conditions may have stimulatory effect on LNB. The other soil invertebrates and litter fauna show stimulatory effect only on *Azatobacter* and they also have a positive correlation with earthworm populations. Such observations have also been made under green house conditions.

Correlation between the above ground and belowground biodiversity
The above ground flora mostly has a positive influence on soil micro flora whereas a significant influence of tree population on earthworms is observed. The other soil invertebrates are not much affected or negatively affected by the above ground flora (Table 14).

Benchmark Survey of the Study site village
The overall objective of the benchmark survey of the study site village Koothy in Somwarpet, Coorg district, Karnataka was to document farmers' present status of agricultural activities, their land holdings, livestock, economics of major crops/activities, resource inventory, their present farming practices related to BGBD, farmers awareness about BGBD etc.

The data for the benchmark survey was collected through a pre-tested structured schedule from a random sample of 60 out of 160 farm families of the study village. Sample respondent farmers were post classified as small, medium and large farmers based on their landholdings.

A farmer with a landholding of less than 2 ha was considered as a small farmer, farmers with farm size between 2 ha and 4 ha were treated as medium farmers and those farmers who had land holdings more than 4 ha were reckoned as large farmers. The data were analyzed using simple statistical measures such as measures of central tendency (mean etc.), chi-square test etc.

The geographical area of Koothy village is about 962 ha. Agriculture accounts for about 68% of the total village area compared to 19% of forest area. More than 90% of the village population is directly dependent on agriculture for their livelihood. The study region comprises of mostly marginal and small farmers who constitute more than 40%, but the aggregate area owned by them was disproportionately lower. There is a greater inequity in the distribution of land holdings in the study area.

Livestock in the study village largely comprises of cows (23.23% of total livestock population), buffaloes (10.97%) and poultry (51.77%). Animal husbandry is not a major economic activity due to high level of humidity and low milk yield. Major crops in the study village are paddy and horticultural crops including plantation crops. Paddy, the staple food crop, occupies about 24% of the total net cropped area. Horticultural crops like chilies and other vegetables occupy significant area especially during the summer season. The study region is home for plantation crops like coffee, cardamom, pepper etc. The literacy level in the village is very high as more than 90% of the population as well as sample farmers have formal education. The mean literacy level of the farmers who have awareness about BGBD and those who do not have any awareness was almost the same. Most of the respondents were young farmers whose age was about 30 years. The major occupation of the respondents is agriculture and about one third of the families are engaged in agricultural wage labour.

The average annual income of the farmers who have awareness about BGBD is higher (Rs. 61589) than those who do not have awareness about BGBD (Rs. 54304). Out of 60 sample respondents, about 42% were small, 28% medium and 30% large farmers. The average size of land holding of small farmers is 0.9 ha while that of medium and large farmers is 1.5 and 4.35 ha, respectively. More than half (68.33%) of the farmers owned coffee plantations. About 48% of the farmers owned cardamom plantations. About 13% of the farmers owned both coffee and cardamom plantations in the study area.

It is surprising to note that only 45% of the respondents have some knowledge and awareness about BGBD and their uses. The remaining 55% of the respondents do not have awareness about BGBD. In general, the farmers know the existence of various types of BGBD and some of them could identify their beneficial as well as harmful roles. The low awareness of BGBD among the farmers could largely be attributed to lack of sensitizing/extension programmes on the part of the developmental departments on BGBD programmes. The farmers do not have much knowledge about the N- fixing organisms and organisms involved in nutrient cycling.

The common BGBD practices followed by the farmers in the study area are composting, green leaf manuring etc. Incorporation of weeds into the soil is another practice commonly followed by them. Ploughing back paddy crop stubbles and residues to the soil is another major BGBD practice followed.

The major reasons for non-adoption of BGBD practices by the farmers are lack of awareness of GBD, their benefits, lack of technical know-how, non-availability of inputs locally and difficulty in the adoption of BGBD practices.

Table 11. Population density of above groung flora and soil biota in different land use types in year 2004 during pre and post-monsoon seasons.

Species	NF			GL			AP			CP			CoP			PF		
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
D. fakir	66	15	7	18	4	0	30	10	0	25	19	2	111	23	2	-	-	-
D. kanarensis	-	-	-	-	-	-	-	-	-	8	4	4	-	-	-	-	-	-
D. mimuta	-	-	-	-	-	-	-	-	-	9	4	1	-	-	-	-	-	-
D. modesta	36	8	1	-	-	-	-	-	-	21	20	10	56	9	6	25	10	5
D. pellucida	-	-	-	45	19	0	110	26	0	22	11	4	67	7	5	-	-	-
D. somavarapatana	198	32	8	-	-	-	45	10	9	122	78	55	318	56	2	55	35	11
L. mauritii	43	12	2	-	-	-	-	-	-	-	-	-	95	35	9	-	-	-
M. curgensis	-	-	-	-	-	-	-	-	-	-	-	-	109	26	5	40	20	4
M. feliciseta	-	-	-	-	-	-	-	-	-	-	-	-	39	2	10	-	-	-
Metaphire houlluti	87	9	0	-	-	-	-	-	-	10	3	2	161	35	1	66	12	0
Megascolex sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25	9	0
O. beatrix	-	-	-	-	-	-	-	-	-	11	0	0	-	-	-	-	-	-
O. pitnyii	-	-	-	-	-	-	-	-	-	6	5	3	-	-	-	45	11	0
O. castellamus	51	6	0	9	3	0	16	6	2	10	2	4	46	22	8	-	-	-
R. pallida	-	-	-	19	9	0	-	-	-	-	-	-	-	-	-	-	-	-
C. narayani	21	5	3	-	-	-	20	9	0	-	-	-	86	45	13	15	5	0
P. corethrurus	21	5	3	35	14	3	75	20	9	50	30	10	198	68	10	62	15	7

Note: NF – Natural forests, CoP – Coffee plantations, CP – Cardamom plantations, PF – Paddy fields, AP – Acacia plantations, GL – Grasslands

Table 12. Correlation matrix between the soil properties and functional groups.

Soil Property	VAM		PSM		LNB		*Azatobacter*		S. invertebrates		L. invertebrates		Earthworms
	Seasons		Seasons		Seasons		Seasons		Seasons		Seasons		Seasons
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Post
Clay	-0.464*	-0.555*	-0.305	-0.497*	0.545*	0.057	-0.746*	-0.095	0.561*	0.182	-0.546*	0.437*	0.646*
Silt	-0.494*	-0.604*	0.352	-0.715*	0.341	-0.359	-0.860*	-0.298	0.638*	-0.071	-0.210	0.638*	0.408*
Sand	0.408*	0.601*	0.342	0.793*	-0.203	0.116	0.871*	0.314	-0.827*	0.083	0.374	-0.718*	-0.295
Bulk density	0.918*	0.935*	-0.287	0.314	0.105	-0.598*	0.576*	-0.654*	-0.608*	0.825*	0.831*	-0.603*	-0.179
Phosphotase activity	0.652*	0. 567*	-0.509*	0.867*	0.146	-0.136	0.882*	0.149	-0.806*	-0.279	0.449*	-0.797*	0.164
Organic carbon	0.431*	0.408 *	0.686*	0.989*	0.017	0.392	0.890*	0.517*	-0.735*	0.142	-0.004	-0.732*	0.136
Nitrogen	-0.262	0.069	0.407*	0.599*	0.179	0.579*	0.398	-0.813*	-0.479*	0.821*	-0.325	-0.460*	0.282
Potassium	-0.354	-0.029	-0.060	0.302	0.684*	0.337	-0.011	0.473*	-0.350	0.718*	-0.391	-0.350	0.716*
Total phosphorus	-0.649*	-0.499*	-0.532*	-0.811*	0.214	-0.091	-0.941*	-0.151	0.662*	0.267	-0.363	0.631*	0.177
Available phosphorus	-0.449*	-0.375	-0.748*	-0.632*	0.215	-0.111	-0.880*	-0.363	0.622*	0.132	-0.273	0.622*	0.111

Table 13. Correlation matrix between the functional groups**.**

Organism	VAM		PSB		LNB		*Azatobacter*		S. invertebrates		L. invertebrates		Earthworms
	Seasons		Seasons		Seasons		Seasons		Seasons		Seasons		Seasons
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Post
VAM	1.00	1.00	-0.121	0.710*	-0.099	-0.341	-0.533*	-0.193	-0.772*	-0.378	-0.586*	-0.618	0.306
PSM	0.004	-0.556*	1.00	1.00	-0.332	0.902*	0.780*	0.301	0.362	-0.817*	-0.127	0.083	0.013
LNB	0.455*	-0.598*	-0.352	0.902*	1.00	1.00	0.028	0.911	0.173	-0.830*	-0.433*	0.390	0.910*
Azatobacter	0.300	-0.193	0.780*	0.301	-0.028	0.111	1.00	1.00	0.859*	0.184	-0.113	0.833*	0.291
S. invertebrates	0.320	0.259	0.362*	-0.817*	0.173	-0.830*	0.859*	0.184	1.00	1.00	0.067	-0.527*	0.402*
L. invertebrates	-0.784*	-0.038	-0.127	0.083	-0.433*	0.390	-0.113	0.833*	0.067	-0.527*	1.00	1.00	-0.286
Earthworm	0.306	0.306	0.013	0.013	0.910*	0.910	0.291	0.291	0.402*	0.402	-0.286	-0.286	1.000

Table 14. Correlation matrix between belowground biodiversity with above ground biodiversity.

Organism	Trees		Shrubs		Herbs	
	Seasons		Seasons		Seasons	
	Pre	Post	Pre	Post	Pre	Post
VAM	-0.622*	-0.373	-0.176	0.469*	0.787*	0.400*
PSM	0.516*	0.379	0.806*	0.653*	0.652*	0.224
LNB	0.216	0.095	-0.006	0.563*	0.379	-0.298
Azatobacter	0.923*	0.540*	0.874*	0.441*	0.518*	-0.300
Soil invertebrates	0.934	-0.199	0.598*	-0.479*	-0.501*	-0.633*
Litter invertebrates	0.199	-0.494*	-0.479*	-0.182	-0.418*	-0.232
Earthworm	-	0.433*	-	0.206	-	-0.299

Final Technical Report. Conservation and Sustainable Management of Below-Ground Biodiversity in the Kerala Part of the Nilgiri Biosphere Reserve - Phase I.

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The benchmark site of the Project on Conservation and Management of Belowground Biodiversity (BGBD Project) established in the Kerala part of Nilgiri Biosphere Reserve, is located in the micro-watershed of Chaliyar River. The study site covers land use systems such as primary forests, secondary forests, managed plantations, agroforestry systems and annual crop based systems. Among different landuse systems, the semi-evergreen forests with 67 tree species are rich in tree species diversity. These forest patches are free from human disturbance as indicated by the RISQ value (1.16) and closed canopy nature (LAI 4.24 to 4.92). On the other hand, moist deciduous forest patches are being repeatedly disturbed and trees of smaller girth classes are lesser than those of higher girth classes and the RISQ value is significantly more (3.83) than that in semi-evergreen forest patches. Forest patches closer to the agricultural lands are highly degraded with the total density and basal area of tree community is less than 25% of that recorded in the semi-evergreen forests and 10% of that recorded in moist deciduous forests. Repeated extraction of poles and other biomass and grazing are responsible for the degradation of these patches. In the teak plantation, density and basal area of teak are significantly less in water-logged area than in uplands. Growth of teak in these plantations is in generally poor as indicated by the tree gbh which is less than 20% of the expected value for the trees of same age (25 year old). In tree- based cropping systems, tree density, basal area and species number vary from points to points depending on the crop combination, age of the farm and management practices adopted by farmers. When different subsystems of tree-based cropping systems are compared for the contribution of trees maintained for green leaf manure production to the total Importance Value Index (IVI) of tree community, the values are high in polyculture homegardens followed by polyculture farm lands. In many plantations, cultivation and management of green leaf manure species are totally absent.

Out of 171 vascular plant species recorded during the course of this study, 25 species are legumes. Wherever the contribution of leguminous shrubs is relatively more it is due to the growth of *Cassia occidentalis* and *Desmodium gangeticum*. On the other hand, wherever the contribution of leguminous herbs is relatively more it is due to the profuse growth of *Mimosa pudica, Centrosema pubescens* and *Desmodium triflorum* in poorly managed systems. In well managed systems generally *Vigna unguiculata* is being cultivated and thus it contributes much to the IVI of herb community. In case of cashew plantations with poor soil and exposed laterite blocks, *D. triflorum* (a leguminous herb) forms almost a thick carpet covering the soil. Further studies on the role of *D. triflorum* in soil and water conservation and soil fertility improvement are needed.

The moist deciduous forest located near human habitation are highly degraded and possess sparse vegetation and nutrient poor compact soil when compared to the similar kind of forests located away from the human habitation.

Though these two forests are originally similar in terms of aboveground vegetation, the degraded forests showed relatively higher value for ant density and diversity. Thus ants, particularly *Lobopelta sp.* and *Leptogenys sp.*, could be considered as indicator species of forest disturbance. In the study area, majority of the current landholdings were under paddy cultivation about 252 years back. Thus, similarity in terms of belowground biodiversity between paddy fields and other land use systems derived from paddy fields could be pronouncing. However, absence of some of the soil faunal elements in certain land use systems recorded in the study area could be attributed to the differences in the crop combinations and management practices. For instance, low density of earthworm in annual crops and areca nut mixed with annual crops may be attributed to the excess use of inorganic fertilizers and pesticides. It may be pointed out here that among the endogeic worms *Parryodrilus lavelee and Pontoscolex corethrurus s*howed maximum availability in a variety of land use patterns. It may also be concluded that since these two species have a wide tolerance to land use changes, they may be suitable for land restoration purpose. It may also be mentioned here that apart from the season of sampling, land use history, land use pattern, crop combination etc. the sampling technologies adopted decide the qualitative and quantitative information that can be obtained on each group of soil fauna. Thus the sampling technologies to estimate different faunal groups need to be standardized considering both the faunal group under study and the land use systems.

In the study area, plantations of teak, rubber and cashew are located in almost similar terrain to that of moist deciduous forest. Moreover, age of these plantations ranged from 3 to 25 years and before that they too were representing either degraded or good moist deciduous forests. Comparatively high diversity of AM fungi in soils in cashew plantations, degraded forests and teak plantations than that in moist deciduous forests situated away from human habitation indicate that conditions in these soils are highly suitable for the proliferation of a host of mycorrhizal fungi. Though more studies would be required to arrive at any firm conclusions, the available data show that plant dependency on mycorrhiza is apparently more in highly degraded sites.

In general, dependency of majority of the farmers in the study area on croplands for the livelihood is relatively low, either due to small size of the landholding or due to attractive economic return from their non- farming activities. Studies carried out in the cultivated lands also indicated that organic carbon, exchangeable calcium, magnesium and potassium were considerably lesser than the level required for the optimum crop yield. It was also recorded that the contribution of trees and understorey species maintained for green leaf manure production to the total IVI of tree and understorey plant communities are significantly low or nil. Further analysis of the crop management systems in the region also revealed the fact that cultivation and management of leguminous crops with a view to obtain green manure and soil fertility management in almost all croplands are neglected. Even the application of green leaf manure, farmyard manures, cultivation of cover crops which are required to sustain the crop yield and soil fertility are not being adopted adequately. Over-harvest of biomass without sufficient nutrient input is leading to the loss of nutrients from the crop lands. Similarly, application of heavy dose of chemical pesticides at frequent intervals into croplands can be attributed to the loss of below ground biodiversity. In forest teak plantations, removal of litter from soil surface for fuel and mulching has been identified as one of the major causes for the decline in the soil moisture, extractable phosphorus, exchangeable potassium and exchangeable magnesium. Studies also revealed that some of the faunal characteristics are either absent or sparsely represented in a given land use system. It was recorded that in the unmanaged systems the root colonization of vesicular arbuscular micorrhizal (VAM) fungi were more than in some of the well managed mono-cropping systems. Thus it was clear that in unmanaged systems plants are more dependent on mycorrhiza for growth. Further analysis of data indicated that majority of the land use systems were not significantly different from the un-managed plantations in terms of per cent root colonization by mycorrhiza indicating that these plots are also poorly managed.

Results of quantitative estimation and diversity of soil legume nitrogen fixing bacterial (LNB) population in different land use systems in the study area indicated the fact that the rhizobial population in polyculture systems was significantly more than in annual crop based systems. The higher population of rhizobia in soil during pre-monsoon season than in post-monsoon, in all the land use systems indicated that pre-monsoon season would be an ideal season for soil rhizobium estimation. Among the thirteen species of naturally growing legumes in the study area, *D. triflorum* produced most profuse nodulation. Thus the wild legumes such as *D. triflorum* could be a potential source of green cover crops. Conventional physiological and morphological techniques indicated that the LNB isolates belonged to five genera viz. *Rhizobium, Mesorhizobium, Sinorhizobium, Bradyrhizobium* and *Allorhizobium.* The study also revealed the fact that the most of the isolates which originated from degraded forests, teak plantation and paddy field utilized the sugars better than isolates from other sites.

Genetic diversity studies of inter box elements using box primers involving the eighty LNB isolates showed that 100 percent of the loci were polymorphic indicating high level of genetic diversity among the isolates. Gene diversity varied from 0.0722 to 0.4888 with a mean diversity of 0.2949. Molecular studies based on partial 16S rDNA sequencing and analysis of sequence data could identify 4 LNB isolates from Kerala part (KFRI isolates). These isolates belonged to *Klebsiella* sp., *Agrobacterium tumefaciens, Burkholderia cepacia* and *Burkholderia* sp. Further studies on the genetic diversity studies conducted at G.B Pant University of Agriculture and Technology on 13 LNB cultures isolated from trap plants (cow pea) showed that the LNB isolates from Kerala part of NBR were more diverse genetically than the isolates from Karnataka part of Nilgiri Biosphere Reserve and from Nanda Devi Biosphere Reserve.

In the study area, the respondents are literate and have the tendency to imbibe new knowledge and techniques to improve their croplands. Thus attempts to promote suitable activities for the conservation and management of belowground biodiversity are expected to become successful. In this context, post-project meetings were organized to present the results of the study before the farmers and land managers. The participants agreed with the fact that continuous cultivation without external application of organic manures and lack of efforts to conserve organic matters in the systems are the reasons for low productivity and soil organic matter depletion in different cropping systems. Farmers also recognized the competition between the weed community and crop community as an important cause for difficulty in maintaining the optimum crop yield. As already indicated in the landscape of Chaliyar River Watershed, the study recorded a faster rate in landuse and land cover changes. The farming community also expressed the view that the conversion of one cropping system to another is more frequent resulting in the increased soil erosion and runoff rates. Considering these aspects, four strategies viz. (a) application of green leaf manure, (b) application of plant growth promoting microorganisms and earthworm rich compost, (c) reduction of nutrient loss from the croplands, and (d) growth of leguminous and/ or biomass transfer species in the crop lands for maintaining soil fertility, sustainable yield and to enhance density and diversity of soil biota in different cropping systems, have been identified. During the second phase of the project on-farm participatory experiments to demonstrate the usefulness of these strategies and also disseminate information and technology to the wider user groups may be undertaken.

Technical Report. Conservation and Sustainable Management of Belowground Diversity in the Nanda Devi biosphere reserve - Phase I (2006)

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The Himalaya has been a perennial source of attraction, curiosity and challenge to human intellect throughout the ages. The diversity, copiousness as well as uniqueness of the plant communities in various habitats for a long period retained sound and aesthetic environment of the Himalayas. However, in the recent past due to excessive exploitation, unplanned land use, natural disasters, and several developmental processes, accelerated deterioration of vegetation or loss of individual species, in the localities or regions has changed the scenario. Due to multiple stresses and depletion of vegetation and habitat, the main concern of the current generation is the conservation of biodiversity both below ground and above ground. This technical report is out of the concern for biodiversity conservation of the Himalayan environment and ecosystem. It presents the results of a study of the Himalaya region and specifically in the buffer zone area of Nanda Devi Biosphere Reserve (NDBR) and adjoining areas with following objectives: (1) Inventory and identification of below ground biodiversity (BGBD) in relation to physicochemical, properties of soil and above ground biodiversity in cultural and protected landscapes comprising a range of land use/land cover types, (2) Applicability of available methods for sampling BGBD in the Himalayan landscapes, (3) Effect of land use, soil fertility and estimation and assessment of nodulation, *Rhizobia* diversity/legume growth and their impact on soil fertility, (4) Indigenous land use (traditional agriculture) related to BGBD and its linkages to above ground biodiversity and ecosystem functions, and (5) To enhance awareness, knowledge and understanding of BGBD importance to sustainable agriculture production by the demonstration of the methods for conservation and sustainable management.

The Buffer Zone of Nanda Devi Biosphere Reserve (NDBR) has two important elevation levels. The high altitude (2200-3100 masl) and the mid altitude level of between 600 and 900 m asl). It is at these two elevation levels that the study areas were located. Two windows one at high altitude and the other at mid-altitude were identified. A total of 126 grid points were located at the high altitude level whereas 121 grid points were located at middle altitude level. The climatic conditions for the high altitude area consists of three distinct seasons-summer season (April-June), rainy season (June-September) and winter season (October-February). Average annual rainfall is 930 mm. About 47% of annual rainfall occurs over a short period of two months (July-August) featuring a strong monsoonic influence. Monthly maximum and minimum temperatures range between 24.0 °C to 14.0 °C and 3.0 °C, respectively. Parent material is crystalline rock comprising garnetiferous mica schists, garnet mica quartz schists and mica quartzite. The soils, in general, are loam to sandy loam and well to extremely well-drained. The monthly maximum and minimum temperature ranges between 27.2 °C to 15.3 °C and 16.0 °C to 2.2 °C. June and August are the hottest months of the year with an average temperature of (27 °C) and (16.04 °C). Frequent snowfall during winter occurs from November to March. Snow accumulates during winter and may not melt completely until the end of April or mid May. Connective storms accompanied by hail are frequent during the pre-monsoon season (February-March).

Land use and land cover in the area was mapped by the visual interpretation of IRS standard geocoded false color composite at scale 1:50,000. Vegetation structure and composition varied with altitude and terrain features. *Pinus wallichiana, Cedrus deodara, Cupressus torulosa, Abies pindrow, Pincea smithiana, Betula* spp. and *Quercus* spp. are the dominant trees. Settled terrace farming is confined to less than 1% area of buffer zone, with a mixture of leaf litter and livestock excreta used to manure crop fields. The reserve is covered under the Himalayan biogeographic province 2A of India and is richly endowed with floral and faunal biodiversity. About 600 vascular plant species, including a number of rare, endangered and threatened taxa (e.g. *Dactylorhiza hataziera, Aconitum heterophyllum, Swertia chirayata, Taxus baccata)*; 18 mammals including seven endangered species including Snow Leopard *(Panthera uncia)*, Black bear *(Celenarctos thibentamus)*, Brown Deer *(Urcus arctos)*, Musk Deer *(Moschus chrysogaster)*, Bharal *(Pseudois nayaur)*, Himalayan Tahr *(Hemetragus jemlahicus)*, Serow *(Capricornis sumatraensis)*, Kokla Pheasant *(Purasic macrolopha)*, Western Tragopan *(Tragopan melanocephalus)*, Golden Eagle *(Aquila mipalansis)*, Black eagle *(Letinaetus malayensis)*, Bearded vulture *(Gypatus barbatus)* are reported.

In the entire buffer zone, rain-fed agriculture on steep terraces is the predominant form of land use, while only about 22.4 ha (8 percent of the total cultivated land) is irrigated. The major crops cultivated in the middle and high altitudes of buffer zone are *Amaranthus* spp (amaranth), *Phaseolus vulgaris* (kidney bean), *P. lunatus* (a kidney bean locally known as chhimi), *Fagopyrum* spp. (Buckwheat), *Eleusine coracana* (finger millet), *Panicum miliaceum* (hog millet), *Solanum tuberosum* (potato), and *Hordeum himalayens* (naked barley). Medicinal plants like *Dactylorhiza hataziera, Sellinum wallichianum, Angelica glauca, Aconitum heterophyllum, Berginia ciliata, Allium strachei, Allium humile* are also cultivated by the farmers of the high altitude. A variety of horticultural trees (apple, apricot and walnut) that provide fruits and fuel are grown on the raised margins of the rain fed terraces in the lower and middle elevation zones. Seasonal and off seasonal vegetables such as cucurbits, ginger, cabbage and green vegetables are grown in the kitchen gardens. The mid-altitude area has a climate where 70% of the total rainfall that occurs during rainy season (mid June to September) snow fall is rare in the area but winter season is quite cold and windy (October-March). High velocity winds are prominent during the spring season (March-April) season. The region lies at the catchment of river Alaknanda. Rain fed and irrigated land use systems are important agriculture ecosystems in this area with the former as a predominant form. Land holding of the farmers are scattered at the terrace fields on the hills. Paddy, Millet, Maize and pulses are the crash crops of Kharif (April-October) season while Rabi season (October-May) includes crops like wheat, barley, mustard, lentils and peas. The farmers of this region generally cultivate a variety of crop species and their numerous varieties in rain fed agro ecosystems to meet their food requirements throughout the year commonly known as "*Barahnaja"* or mixed cropping in the more scientific terminology is practiced pulses are grown in particular and in a single field about 12-20 types of different crops are sown.

Soil organic carbon decreased with depth in all land use types but the pattern of this change differed between land uses. In home-gardens, upper 30 cm of soil had almost similar concentration of organic carbon whereas in other land uses 0-10 cm layer had higher concentration followed by 10-20 cm and 20-30 cm. Irrigated agriculture was richer in organic carbon compared to forest soils if the upper soil layer 0-30 cm was compared. However, the carbon concentration in the whole soil profile (0-100 cm), there seemed to be no significant difference between agriculture and forest lands with home-gardens showing the highest concentration. Root biomass decreased with depth in all land use/cover types but the pattern of this decrease varied with depth. Irrigated agriculture, rainfed agriculture and scrub showed negligible root biomass in soil depth >10 cm. In contrast, significant amount of root biomass was observed in deeper soils (30-100 cm) in forests and homegardens. Total root biomass across the soil profile showed a trend of oak forest > pine forest > abandoned agricultural land > home-gardens = irrigated agriculture = rainfed agriculture = scrubland.

Species composition of tree community significantly varied in the landscape. Some species such as *Grewia optiva*, *Bauhinia purpurea* and *Celtis australis* were not found in forest lands. Species like *Ficus auriculata* were found in agricultural as well as forest land. Mean tree density varied from 52.8 in irrigated farm land to 1099.4 trees per ha in home-gardens. Basal area varied from 3.6 m square/ha in irrigated farmland to 28.2 square meter/ha in oak forests. Amount of litter lying on the soil surface in forests was several times higher than that in the cropped or abandoned agricultural lands, even though huge quantities of forest leaf litter was removed for preparation of traditional farmyard manure. Home-gardens have litter mass higher than cropped lands but lower than the forest litter mass.

The people inhibiting in buffer zone villages of NDBR belongs to two ethnic groups viz. Indo-Mangoloid (Bhotiya tribes) and Indo-Aryan. However the people inhabiting particularly in Niti valley belong to the Tolchha community, which is one of the three sub communities of Bhotiyas. Except the residents of Reni, Peng, Lata, and Tolma villages, all Tolchha Bhotiya households have two permanent dwellings, one at the higher altitudes (2400-3500 masl) and another at the lower elevations outside the buffer zone (800-1500 masl). This community has its own culture, tradition and religious beliefs. The major occupation of the community has been sheep rearing and agriculture, with agriculture taking the primary roleover pastoralism. Average family size of the selected villages comprises about 6.0 persons per family, while the livestock possession per family was estimated at 6.0 cattle (excluding sheep and goat as now only few families having these particular animals), whereas per capita land holdings of the selected villages was recorded at 1.09 hectare. A total of 217 households were surveyed at both the locations (94 households at low altitude and 123 households at high altitude.

The households were interviewed through structured Questionnaires. In selecting the villages for data collection emphasis was paid to make the sample families truly representative of the whole population with respect to the income groups and land holdings. The range of percentage of sample households was between 31.43% in Bedanu to 76.92 in Tolma. About 22% males and 49% females were found to be aware about the damage caused by particular insects in the rainfed and irrigated agriculture in the lower elevation, whereas it was found that about 30% males and 67% females are aware of infection caused to crop due to diseases in root and those that are seed born. About 25% villagers of the area were found to engage in spraying ash in their kitchen garden crops i.e. Onion and Garlic kitchen gardens but they were unaware of the fact behind this indigenous practice and the reason behind was the lack of scientific awareness as well as extension activities in the village. Only about 7% males and 10% of females among the total respondents were aware about the beneficial role of spiders and earthworms in their crop lands as well as other land uses and rest of them were of the opinion that earthworms were harmful to their crops. 99% of the respondents were also aware of the beneficial aspects of applying and using tree leaves for preparation of FYM and its role in agriculture. At high altitude about 33% male and 66% female respondents were aware of insect presence in agriculture, about 43% male and 56% female were found aware about harmful insects. Besides, in most of the cases more than 40% of respondents among male and female were aware of crop seed infections, and use of FYM etc. However, less than 10% of the respondents were not aware of extension activities, benefits of earthworm etc.

Macrofauna were segregated from litter layer, and 0-10 cm, 10-20 cm and 20-30 cm layers of soil standard size monoliths following a systematic grid based sampling design. Further, sampling was done covering all the three seasons, April month in pre-monsoon warm season, July in monsoon season and October in post-monsoon season. In low elevation zone, earthworms showed the highest density during monsoon season in agricultural land use, during post-monsoon season in oak forests and similar abundance during pre- and post- monsoon in pine forests. In higher elevation zone, earthworms were found to be absent in alpine pasture and *Cedrus* forests, but present in all types of agricultural land uses. Home garden and medicinal plant cultivation area showed the highest density during post monsoon season, potato field during pre-monsoon and a similar density during pre and post monsoon period in pea cultivation area. Home-garden was the only land use where earthworms occurred in all seasons. Land use effect on earthworm biomass in lower elevations was not as marked as in higher elevations. Oak forest, pine forest, home-garden and rainfed agriculture showed almost similar earthworm biomass at lower elevations. On the other hand, at higher elevations, home-garden showed more than three-fold higher biomass as compared to medicinal plant or pea cultivation. The effect of land use on biomass of earthworms showed the same trend as that on density. Two species were sampled from higher altitudes compared to six species from lower altitudes. *Dendrodrilus rubidus* occurred only in high altitude agroecosystems, *Aporrectodea caliginosa* in all high elevation agroecosystem types and home garden system in lower altitudes and, the remaining six species viz., *Lannogaster pusillus, Metaphire houlleti, Ocnerodrilus occidentalis, Metaphire anomala, Amynthas corticis* and *Drawida nepalensis* only in agroeceosystms and forest ecosystems at lower elevations.

At lower elevations, oak forests showed the lowest hymenoptera population during pre-monsoon and monsoon months, while there were no significant differences in population size in different forests and agroecosystems during post monsoon. Rainfed agriculture showed higher density during monsoon and post monsoon period compared to irrigated agricultural land use, these two land uses showed similar numerical abundance during pre-monsoon season. Isoptera individuals were altogether absent in higher elevation zone. In lower elevation zone, significantly higher density was noted during monsoon season in all land uses except homegardens where numerical abundance observed during monsoon and summer did not vary significantly. The highest coleopteran population was observed during monsoon season in all land uses at lower elevations except irrigated agriculture where this group showed highest abundance during summer season followed by monsoon, with no significant difference between the two seasons.

The magnitude of the effect of land use on coleopteran abundance in terms of biomass differed from that in terms of numerical abundance. Biomass in post-monsoon season in homegardens was >6 times higher than that in other land uses at lower elevations, while different land uses did not differ in terms of numerical abundance. Myriapods occurred in all land use/cover types in higher elevations and only in pine forest and rainfed agriculture at lower elevations. Dictyoptera population was altogether absent in higher elevation zone and in one land use/cover type at lower elevations, viz., irrigated agriculture. Pine forest at lower elevation was the only land use where this group was sampled in all the three seasons. Diptera occurred in all land uses but not in all seasons in all land uses. Thus, they were sampled from oak forest and homegardens at lower elevations only in one season, during pre-monsoon in the former and monsoon in the latter. Though population size varied, significant differences were not observed. Hemiptera individuals were sampled from all land uses, except alpine pastures. Homegarden and irrigated agriculture at lower elevations had significantly higher abundance at lower elevations compared to other land use types. Orthoptera population was absent in pine forests at lower elevations and alpine pastures and food crop cultivation area in higher elevations. Differences between land uses were not significant.

There were 34 species of mycorrhiza, 13 belonging to the genus *Acaulospora*, 3 to *Gigaspora*, 8 to *Glomus* and 10 to the genus *Scutellospora* were sampled in soils collected from different land uses in the lower elevation village landscape. It may be noted that about 3% of spores in abandoned agricultural land to 13% in oak forests could not be identified at species level. *Acaulospora lacunosa* was sampled only from pine forests, *Gigaspora geosporum* only from abandoned agricultural land and, *Scutellospora dipurpurascea* and *S. scutata* only from irrigated agriculture. Twelve species occurred in all land uses but the degree abundance varied between sites. Nematode abundance in 0-10 cm soil layer was significantly higher than that in 10-20 cm layer in all land uses but the rate of decline differed between species. The steepest decline was observed in home-gardens. The trend in abundance in 0-10 cm layer was irrigated agriculture = rainfed agriculture = abandoned agriculture > home-garden = scrubland = pine forest = oak forest.

Effects of land use change on earthworm diversity and biomass in Sumberjaya, West Lampung. Jurnal Sains dan Teknologi 12 (1): 14 – 20. (ISSN: 0853-773X) (2006).
S. Murwani, W.S. Dewi and K. Hairiah
Land conversion from forest into agricultural system would cause significant changes in the soil (and its litter) conditions which in turn could affect the life and distribution of soil biota therein, especially for earthworm. The objective of the research was to record the origin, functional groups, abundance, diversity and biomass of earthworm as affected by land use change in Sumberjaya, West Lampung. Earthworm was sampled from the monolith in seven different land uses. A total of 10 earthworm species were found in the study site although its diversity was not significantly different among land uses (ranged from 0-5 species). Native species were only found in the forests, whereas, exoctic species thrived well in agricultural lands. Most epigeic and endogeic species were distributed in 0-10 cm. land use change from forest into agriculture decreased earthworm biomass as did for soil organic matter and soil litter.

Diversity and abundance of soil-borne pathogenic fungi in various land-use systems in Sumberjaya, Lampung. Jurnal Hama dan Penyakit Tumbuhan Tropika 6(2): 107 – 112. (ISSN: 1411-7525) (2006).

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The study aimed at investigating the effects of land use systems on the diversity and abundance of soil-borne pathogenic fungi in different land use systems. Soil samples were collected from Sumberjaya area, West Lampung during October 2004. A total of 88 soil samples were collected from seven land uses systems: (1) undisturbed forests, (2) disturbed forests, (3) shrubs, (4) polyculture coffee, (5) monoculture coffee, (6) food crops, and (7) horticulture crops. The soil samples were laboratory analysed to isolate and enumerate viable fungal propagules using bioassay procedures by a modified most probable number technique. The results of the study showed that land use systems had different impacts on diversity and abundance of soil-borne pathogenic fungi.

The diversity declined in non-agricultural systems from undisturbed forests to disturbed forests, shrubs, and polyculture coffee, and then increased in agricultural systems from polyculture coffee to monoculture coffee, and then food crops. In horticultural crops, however, the diversity was lower than that in the food crop systems. The abundance had a similar trend except in horticultural crops that showed the highest population. The occurrence of soil-borne pathogens was different across land use systems. *Fusarium* spp. dominated all land uses, except the shrub that was dominated by *Curvaria* spp. *Botryodiplodia* spp. occurred in undisturbed and disturbed forest, decreasing in shrubs and then disappearing in the other land uses. The occurrence of *Phytophthora* spp. and *Pythium* spp. was limted in undisturbed and disturbed forests then disappeared in shrubs, polyculture and monoculture coffee, but increased significantly in food crops. *Rhizoctonia* spp. only occurred in undisturbed forests.

Increasing potential distribution of crop pest termites *Odontotermes* spp. after forest conversion to coffee based agroforestry system: Effects of changing in micro climate and food availability on population density. Agrivita (in press) (ISSN: 0126-0537) (2006).

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Genus *Odontotermes spp.* is commonly found as a pest in agricultural and forestry land use systems. Unfortunately the availability of ecological data related tomits link with the environment is scarce. On the other hand, a better understanding on the ecology of *Odontotermes* spp. is needed to control its population in any agro-ecosystem. The measurements on population density and diversity of termites were done on farms owned by farmers in Sumberjaya, West Lampung in janury till April 2004, by comparig (a) the natural forest as a control, (b) forest remnants, (c) multistrata shaded coffee with fruit trees as well as the nitrogen fixing trees (*Erythrina sumbubrams* and *Gliricidia sepium*) as shading trees, (d) monoculture (sum) coffee system, (e) monoculture food crop system, (f) horticuoture system, and (g) degraded land such as *Imperata* grassland. In the Sumberjaya Benchmark site, the termite diversity was rather high, i.e. 15 genera and 39 species. Forest conversion to agriculture land lled to declining termite diversity from 13 genera in the natural forest to 7 in the forest remnants, 3 genera in the agroforestry coffee based systems to 5 genera in monoculture coffee system to 3 genera in the annual food crop system to 2 genera in the *Imperata* grasslands and 2 genera in the in the horticulture system. Wood eating termites *Odontotermes denticulatus, Odontotermes sarawakensis* and *Odontotermes* sp. H. which potentially appear as pests in agro-ecosystems. Development of *Odontotermes* spp. has closer link to the changes of soil temperature and soil moisture (as a result of a reduction of tree canopy cover) rather than food availability after forest conversion. Maintaining aboveground biodiversity such as in agroforestry complex systems is one option of reducing *Odontotermes* spp. through its effect of soil micro-climate change and litter with various qualities. Land use change was clearly seen to be related with the change in soil biodiversity in Sumberjaya, but its impact on its ecological function is not yet still fully understood. Further studies are therefore still needed to improve the strategy of land management for healthy agriculture.

Conversion of forest to agricultural land: Can agroforestry system maintain earthworm diversity? Agrivita (in press) (ISSN: 0126-0537). (2006).
W.S. Dewi, B. Yanuwiyadi, D. Suprayogo and K. Hairiah
Forest conversion into agro-ecosystem either tree-based or annual crop-based may affect earthworm diversity. The lower plant diversity in agricultural systems due to more open soil surface changes the earthworm community. The aim of the research was to quantify the population density and diversity of earthworms of different land use systems after forest conversion. The research was conducted at Bodongaya, Sumberjaya area of West Lampung during the rainy season from January to March 2004. The research was an exploratory experiment based on the survey of population density and diversity of earthworms in seven land use types owned by the community, which were compared to remnant forests. Earthworm samples were collected from soils monoliths (25x25x30 cm) by hand sorting at sampling points within Conservation and Sustainable management of Below-Ground Biodiversity (CSM-BGBD) project site windows.

Ten earthworm species were exrated for seven land use systems in Sumberjaya: four native species and six exotic species. Forest conversion resulted to three native species disappearing i.e., *Metaphire* sp*., M. javanice* group, and *Megascolex* sp. Anthropogenic disturbance resulted to *Pontoscolex corethrurus* as a dominant species in agricultural ecosystems in Sumberjaya. Nevertheless, a high diversity index (0.76) was obtained in coffee in an agroforestry system, implying that those systems provide a favourable condition for earthworm communities. The said, the body size of the earthworm in the agroforestry system was smaller than the ones in the forest systems. The small body size was linked to a decrease in soil moisture content and the amount of coarse organic material in the agroforestry systems.

Impact of forest conversion to coffee-based agroforestry systems on rate of nitrification: Inventory of population and activity of nitrification bacteria. Agrivita (in press) (ISSN: 0126-0537). (2006)
Purwanto, E. Handayanto, D. Suprayogo and K. Hairiah
Forest conversion into intensive agricultural systems lead to sudden changes of the soil surface microenvironment, changes in litter input (quantity and quality) and affects the activity of soil organisms such as nitrifier bacteria (NH_4^+ oxidizers and NO_2^+ oxidizers), nutrient cycling and other soil processes. The aim of this research was to measure the concentration of mineral N (specifically NH_4^+ and NO_3^-) in the soil solution related to the population and activity of nitrifier bacteria of different land use systems and its nitrification potential.

The research was an explorative experiment based on a survey in Bodongjaya, Sumberjaya, in West Lampung. It was carried out during the rainy season of March 2004 to March 2005. Soil samples were collected at 0-30 cm depth in seven land use kinds having forest remnants as control, multistrata shaded coffee with fruits and timber trees as well as nitrogen fixing shade trees, sengon *(Paraserianthes falcatari)*-shaded coffee, *Gliricidia*-shaded coffee, sun-coffee (monoculture), *Gliricidia*-shaded coffee with cover crop *Arachis pintoi*, and intensive horticulture. The coffee plots owned by farmers were selected when the coffee trees were 7-10 years old. The measurements in each land us was carried out twice.

The effect of the different land use types were significantly different ($p<0.05$) on total N and nitrification potential, and very significant ($p<0.01$) on the concentration of N-NO_3^- (but not in the concentration of N-NH_4^+). The average concentration of N-NH_4^+ in all the land use types was about 0.6 mg kg^{-1} to 1.0 mg kg^{-1}. The highest concentration of N-NO_3^- was found in horticulture systems (28 mg kg^{-1}), which was five times higher than in the other land use systems. High concentrations of N-NO_3^- in soil solutions was significantly correlated (R^2=0.91) to high nitrification potential. The results of biological measurements, however, shows no significant ($p>0.05$) effect of different land use types on the population density of nitrifier and heterotrophic bacteria. The higher concentration of NO_3^- in the soil solution and nitrification potential found in the intensive agricultural systems indicated that the nitrification process went more rapid than in the forest remnant and agroecosystems, it may decrease N use efficiency and increase more risk of N loss to the deeper layer.

BGBD review paper entitled 'Soil Biota, Ecosystem Services and Land Productivity' currently in press in the Ecological Economics journal - Special Issue Ecosystem Services and Agriculture.

Soil Biota, Ecosystem Services and Land Productivity

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

Work in progress

Economic Evaluation of the Contribution of Below Ground Biodiversity: Case Study of Biological Nitrogen Fixation by Rhizobia

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Although it is a common knowledge that soil micro-organisms form an important constituent of below ground biodiversity and provide key ecosystem services, such knowledge is often not leading to the formulation of favourable policies to conserve the soil micro-organisms. Applying the knowledge gained from several experiment station and on-farm research (supplemented with necessary assumptions) on FAO-sourced secondary data on soybean (*Glycine max*) from 19 countries in Africa, this study attempted to increase the visibility of the important activities of micro-organisms by quantifying the economic value of nitrogen fixation often associated with the activities of legume nodulating bacteria (LNB). The computation of economic value of nitrogen fixation was mostly based on the method of cost replacement or cost savings of the fixed nitrogen compared with the mineral nitrogen fertilizer required to attain the level of nitrogen fixed. Result shows that the economic value of the nitrogen-fixing attribute of soybean in Africa, especially the promiscuous varieties, is quite high and in total ranges from about US$197 million in 2002 to about US$203 million in 2004 with a mean of about US$199 million across the years (2002, 2003 and 2004). The study concludes with recommendations on the various ways of increasing the chances of smallholder farmers benefiting from the nitrogen-fixing attribute of LNB, especially since many of them cannot afford adequate quantities of inorganic fertilizers required for increased crop productivity.

Inventory of below-ground biodiversity in relation to land use, Vol. 1. Description of the BGBD benchmark areas in Brazil, India, Indonesia, Ivory Coast, Kenya, Mexico and Uganda. BGBD project series, report nr. 2007.

E.J. Huising and P. Okoth (Eds.)

TSBF-CIAT, Kenya

This project report is a compilation of reports and papers submitted to the Global Coordinating Office that describe the benchmark areas that have been selected for the inventory of BGBD. The benchmark areas are described in terms of the soil characteristics, land use characteristics as well as socio-economic characteristics of the area. The benchmark sites are all located within biodiversity hotspots and generally part of the area is protected as either national park, forest or biosphere reserve or other. The papers give a good general characterisation of the areas, but at the same time highlight the driving forces behind processes of land use change and threats to biodiversity above and below-ground. All the Country Project Components have submitted their reports and currently the final editing of the reports is taking place.

Inventory of Below-ground biodiversity, Vol. 2, Soil ecosystem engineers and litter transformers: Analyses of diversity and abundance of macrofauna species in relation to land use. BGBD project series, report nr. 2007.

E.J. Huising and P. Okoth (Eds.)

TSBF-CIAT, Kenya

The upper Solimões River region (State of Amazonas, Brazil) is home to a highly diverse community of ant species. Pasture fields represent the land use system associated with the lowest ant species diversity in the study areas, and is therefore not to be recommended in regional agroecosystem management schemes. Most taxa of termites in Indonesia (species), beetle (family), or ants (genus) could be found from a minimum of 10 samples. As predicted, the mean diversity, diversity index, and density of termites and beetles in forested samples were significantly higher than those in croplands with those in coffee plantation in between. Diversity and density of termites, beetles, and ants decreased as land use intensity increased. Decrease in ants or beetles diversity correlated with thickness (weight) of litter in which they lived (found). The litter weight tended to decrease along the increasing gradient of land use intensity. In addition, the thicker the litter was, the higher was the diversity and density of ants or beetles.

In Cote d'Ivoire, the soil feeding group of termites seems to be good candidates as biological indicator for forest conversion. Termite abundance, biomass and species richness were generally reduced when forests were cleared or canopy cover reduced suggesting that - along the gradient of anthropogenic impact from primary woodland to maize fields - biomass first decreases, then increases, while diversity diminishes continuously. In Uganda, the findings indicate that land use change to more intensive uses may decrease macrofauna diversity and may also change the composition of taxa within the land use. In Brazil, the diversity in agroforestry sites was lower than expected, but few agroforestry sites were sampled. Assemblage similarity measured by Morisita's index indicated that fallow fields, crops and agroforestry were very close, while pasture was very different from all other systems. Rank-abundance distribution showed that relative abundance in forest assemblages was more balanced, while pasture assemblages were dominated by a few very species. The other systems show intermediate patterns.

The main conclusions from the preliminary analysis are: (1) the traditional crop – fallow system has a termite diversity which is very close to that of the primary forest; (2) pastures seem to be the worst system for preservation of termite diversity; and (3) the mean number of species per transect does not show much difference between land uses, indicating that most of the difference in total diversity is due to species turnover (beta diversity). In the tropical rain forests of the Amazon basin, termite species assemblages can contain between 11 and 93 species, depending on the sampling site. In Mexico, in contrast, there are not site species accounts which may enable one to make valid comparisons. The nine termites species found in the study area were considerably lower than the 27 species reported for the deciduous forests of Chamela, in the state of Jalisco. As expected, tropical forests in Los Tuxtlas had the highest total richness values whereas pastures had the lowest. From the results it is possible to recognize the following gradient of species richness: forests-agroforests-crops-pastures, although average species richness in forests did not differ from those of agroforest and crop systems.

Preliminary conclusions in Uganda are that changes in termite diversity observed across Mabira Forest Reserve and surrounding Agro ecosystems consisted largely of losses of soil feeding species with wood and litter feeders being less affected. In Cote d'Ivoire, the inventory of earthworms showed that multispecies plantations and recurrent fallows were "hotspots" for earthworm diversity. Investigations aiming at developing ecosystem services of earthworm diversity should focus on functional diversity. The role of "decompacting" and "compacting" species in the regulation of soil structure and organic matter dynamics should be highlighted. For this matter *H. africanus* (decompacting species), *M. omodeoi* and *Millsonia* sp (compacting species) will be of interest. Due to the functional importance of earthworms in ecosystem functioning, the sensitivity of their abundance to forest degradation revealed their potential role as bio-indicators. They should therefore be used in bio-monitoring programmes that aim at preventing ecosystems degradation due to anthropogenic activities in forest areas of Cote d'Ivoire.

In Indonesia, earthworms, land use change caused a reduction in number of earthworm species from the forest with 5 species, 3-4 in annual crop cultivation and 2 species in shrub/grass land. But in the tree-base agroforestry, the number of species is the same (5 species). Land use change also resulted in the lost of epigeic species *Methapire* sp. 1 and sp. 2. The distribution of earthworm in the monolith was mostly concentrated in the 0-10 cm soil layer, and the dominant species was the endogeic species *P. corethrurus* and *O. occidentalis,* those species were found in forest. Land use change from forest into agricultural land tended to lower the weight of individual earthworm, and tended to increase abundance and total biomass. Coffee-base agriculture, both intensive (TBI) and less intensive (TBLI), were enable to protect the number of species and earthworm abundance, although the total biomass and individual weight were smaller than those found in the forest.

In Mexico, it should be stressed that two native species where not found in this intensive survey. On the basis of the shape of the native species accumulation curve, we can conclude that these species are probably extinct in this region. Disappearance of *Ramielllona mexicana* could be the result of *P. corethrurus* invasions, whereas forest fragmentation probably play a role in the local extinction of *Ramiellona* sp. Nov. The second main result is related to the high amount of native species in the pastures of San Fernando. One possibility could be that this pattern is the result of the buffering action of the tropical forests that surround these pastures. A second possibility could be related to some kind of management in these pastures that precluded the invasion of exotics (or the maintaining of natives). Investigation of the specific site management practices should help to discriminate between both hypothesis. Further research should be oriented to search for species with potential for the management of soil fertility. One species with this profile could be the native *Balanteodrilus pearsei*, an endogeic species distributed all over the coastal lowlands of southern Mexico. Recent papers have shown that in maize crops mulched with velvetbean (*Mucuna pruriens*), *B. pearsei* can reach very high populations; in addition greenhouse experiments showed that corn production is increased in the presence of both *B. pearsei* and *M. pruriens*.

The fact that no negative interactions exist between *B. pearsei* and *P. corethrurus* (Ortiz *et al.* 2005) is another advantage of this species, that has been found in maize crops of Soteapan and Mirador Saltillo, two towns located close to VC and SF windows (Fragoso in prep.). The diversity of earthworm species in Uganda showed that apart from tea and agro-forestry, all other land use types previously disturbed by human activities had more species than the strict natural reserve. Multiple cropping had the highest number of species (11), followed by sugar cane (8) and secondary forest (7). These observations highlight favourable impact of land use change had on species diversity; possibly due to new ecological niches created that attract different individual species as previously reported.

Grassland of San Fernando in Mexico, was the niche with more abundance and richness of Coleoptera (Beetles). By their density and biomass the larvae of Melolonthidae are the most important rhizophagous and saprovorous beetles in San Fernando. Staphylinidae can be a key group because of their density and diversity and their role in the food web as predators and detritivorous. Carabidae is also an important group because they predate other soil arthropods. Ptilodactylidae are abundant but their habits are not well known although they might have an important role as detritivorous.

Density of soil macro-fauna in India, considering all groups together did not differ significantly by land use type, except that pine forests had significantly higher abundance as compared to oak forests, in lower elevation landscape. However, in high elevation landscape, uncultivated lands had significantly lower density as compared to the cultivated ones. Within cultivated lands, numerical abundance was significantly higher in home gardens as compared to medicinal plant cultivation or pea cultivation area. Effect of land use was more marked in terms of relative abundance of different groups compared to density of all soil fauna pooled together. Thus home gardens and rainfed agriculture at lower elevations had comparable total fauna density but the former had a higher abundance of earthworms and lower of isoptera compared to the latter. At higher elevations, alpine pastures and *Cedrus* forests had similar fauna density but the former had a higher abundance of coleoptera and lower of the 'other fauna' group compared to the latter. Medicinal plant cultivation and pea cultivation areas resembled in terms of total fauna abundance but the former showed markedly higher abundance of eathworms and lower of 'other fauna group' compared to the latter.

The study of macro-fauna in Kenya demonstrates that quantitative changes in diversity and density of soil fauna communities occur when various land use systems are subjected to varying levels of intensification. These changes appear to be associated with management practices such as use of agrochemicals, destruction of nesting habitats, modification of soil microclimate within these habitats and removal of substrate, low diversity and availability of food sources for the associated macro-fauna groups. The significant correlations between some soil macro-faunal groups with selected soil chemical properties shows that, soil chemical characteristics may indirectly play a role in influencing the density, distribution and structure of macro-fauna communities. However there is need to demonstrate how changes in macro-fauna diversity and abundance associated with land use changes affect ecosystem functions and how such functions are beneficial at farm level.

Inventory of Below-ground biodiversity; Vol. 3, Microsymbionts: Inventory of Nitrogen Fixing Bacteria and Arbuscular Mycorrhizal Fungi across various land uses at the BGBB benchmark areas. BGBD project series, report nr. 2007.

E.J. Huising and P. Okoth (Eds.)
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Cultural diversity of the legume nodulating bacteria in Brazil varied among land use types and these effects depended on the trap plant species used. Highest diversity was obtained by using cowpea as trap species and the lowest by using the common bean. In India, a total of 286 isolates from different land use types were obtained. Generally the rhizobial population is low in the Indian Biosphere Reserves (i.e., Nanda Devi and Nilgiri). All morphological/physiological types of rhizobia occur in both reserves but fast growing and slime producing ones dominate the population. In Indonesia, both siratro and *Vigna* were "promiscuous" host trap for rhizobia. Vigna nodulated better than siratro.

A total of 121 isolates were collected from siratro and 228 isolates from *Vigna*. In Kenya, the inventory demonstrated the occurrence of varying abundance levels of LNB in soils from the Kenyan benchmark sites (Embu and Taita), which were largely affected by the land use systems and the eco-geographic differences between sites. Two major LNB groups were characterised: fast and slow growers predominantly found in Taita and Embu benchmark sites, respectively.

In Mexico, under stress conditions such as high temperature, drought, acid or alkaline soils, rhizobial populations may decrease in numbers and diversity. Fungicides that are normally applied to seeds diminish rhizobial survival. Different factors are known to affect the diversity of rhizobia recovered from nodules, e.g. bovine slurry amendments to soil, nitrogen fertilization at levels normally recommended for agriculture, certain agricultural practices and even different bean cultivars. Furthermore, an effect of bean cropping was observed on the diversity of rhizobia recovered from *Leucaena leucocephala* nodules. Following bean crops, no *Mesorhizobium* strains were recovered from *Leucaena* nodules, whereas in a control soil, with no bean previously planted, abundant *Mesorhizobium plurifarium* strains were recovered from *Leucaena* nodules. Rhizobia may also occur due to spreading by dust particles carried by the wind as has been suggested in the dispersal of *Bradyrhizobium canariense*. Therefore, the distribution of rhizobial species may not be restricted to particular sampling points, if so, why are there low numbers of rhizobia in the forest soils? Are the bacteria more labile, dying faster in forest soil or during its sampling, transportation or storage? The results in Mexico could reflect that actual soil conditions may affect the population of rhizobia obtained from the inventory. Then the low numbers may be related to fast recycling of organic matter, to the existence of a stable and large pool of nitrogen, to undefined stress conditions or inhibiting or competing microorganisms in forest soils. This observation deserves further research. Alternatively, low numbers of symbiotic rhizobia may be present in forest soils if legume species are in low density as well. Otherwise the forest rhizobia may not nodulate the trap plant species used. Molecular analysis of environmental DNA samples could shed light on the issue.

In Uganda, multiple cropping and fallow showed the highest population of legume nodule bacteria of *Phaseolus vulgaris* whereas Sugarcane and Grassland had the least. The absence or presence of a homologous legume host in the area probably influenced the rhizobia population. There is need to assess both the quantitative and qualitative relationship between above-ground flora and rhizobia population. High but negative correlations between rhizobial populations and nutrients (N, P, K) indicate that adequate nutrient levels render the legume–rhizobia symbiosis unnecessary. Thus, under sugarcane, which is continually fertilised rhizobia are absent. Rhizobia nodulating *P. vulgaris* and *M. atropurpureum* were more prevalent in all land uses compared to those infecting *G. max*. Beans were mostly nodulated by *Rhizobium* species unlike siratro, which was exclusively nodulated by *Bradyrhizobium* species.

Arbuscular mycorrhizal fungi (AMF)

In Brazil, the total spore abundance was highly variable among samples within the same land use system suggesting that distribution of AMF spores and species are aggregated within a given system. Diversity of AMF tended to be higher in land use systems (LUS) with intermediate levels of disturbance (crops and secondary forest) compared with highly disturbed or undisturbed ecosystems (pasture and forest). In India, it can be concluded that in spite of differences in AMF diversity caused by differences in land use types, there is a good mycorrhizal potential in the soil. Agricultural practices such as mono cropping of only paddy reduced the number of species. There also seems to be seasonal variations with regard to their abundance and occurrence. In Indonesia, agricultural intensification had a minor effect on the distribution of AMF taxa, and AMF spore types, but significantly affected the AMF spore number. The intensification tended to reduce the AMF spore number. Some of AMF spore types were successfully isolated and maintained as pot cultures. These AMF isolates can be screened for the effectiveness in enhancing plant growth in different soil types, and potentially can be developed as bio-fertilizer. In the future its interesting to search whether the AMF taxa can be use as biological indicator for soil fertility and whether the existing AMF spore types population be manipulated through agricultural practices and maintained at such level, that may beneficial for soil productivity.

In Kenya, different AMF species seemed to show preference to land use types, soil nutrient levels, farm management practices and certain landscape characteristics. Observations made during the inventory suggest different ecosystem levels of operation have influence on AMF species. AMF species seemed to operate at different scales with some at smaller scales performing function such as nutrient uptake, at farm level performing functions such as disease control and soil aggregate stability and at landscape level. Further experiments on monitoring the propagules and functions of individual AMF species are needed to confirm the level of operations and processes of individual AMF species. This is necessary if interventions will include manipulation, inoculation to restore degraded lands and increase land productivity. In Mexico, disturbances determined changes in AMF diversity at regional level, and land use determined changes in abundance of spores at local level. Spore formation is highly variable depending on host plants, seasonality, and environmental conditions. For the reason above, also it is necessary to "trap" the fungi in pots. But on the other hand, molecular tools would help to analyze AMF diversity directly from plant roots; some species probably do not produce spores because of the higher costs it represents, mainly comparing them to other dispersal mechanisms costs.

In Uganda, there was the dominance of *Acaulospora, Glomus* and *Scutellospora* in all the land use types. Since AMF spore formation is known to be highly variable, depending on species type (some species may not form spores at all), host plants, seasons of the year, and other environmental factors, the actual conclusions can not be based on only the spore morph types from field soils. Results from trap cultures and determination of MPN will be more conclusive. It is not clear whether the increase in land use intensification decreases mycorrhizal abundance and diversity in the soil. However, farmer practices such as land conversions and agriculture intensification do not only exhaust soil productivity but also influence life in the soil. This was clearly seen in sugarcane plantation with significantly low levels of mycorrhiza.

Inventory of below-ground biodiversity, Vol. 4. Micopredators, decomposers, pathogens, biological control agents: Inventory of nematodes, mesofauna and soil fungi in relation to land use. BGBD project series, report nr. 2007.
E.J. Huising and P. Okoth (Eds.)
TSBF-CIAT, Kenya
Fungi
In Brazil results of fungi inventory showed that intensification of land-use led to differences in fungal populations among the sites investigated, with an increase of colonization by the potential plant pathogenic genus *Fusarium* and an opposite effect on common antagonistic genera. Soils under pasture revealed to be the most disturbed environments. In Indonesia, the fungal decomposers had two functional groups: lignin and cellulose degrading fungi. Diversity and abundance of both lignin and cellulose degraders were different as affected by different land use types. However, there was no conclusive pattern that can be drawn. There is a tendency that the mean of abundance of lignin and cellulose degrading fungi decrease as the land use becomes more intensive.

In Uganda there were several soil-borne phytopathogens. The frequency of *Phytophthora* infection among bait tissues did not differ significantly among LUTs suggesting the tolerance of this genus to a wide range of land use conditions. *Pythium* infection was least in the strict nature forest reserve and but did not differ significantly among the other LUTs. The less acidic soil pH of forest soils or the higher abundance of saprophagous mesofauna may account for the lower incidence of *Pythium* in the strict nature forest reserve. The influence of land use change on the incidence of soil-borne phytopathogens is not well defined. The findings suggest that *Pseudomonas* may be more sensitive to land use changes than either *Pythium* or *Phytophthora* but this requires experimentation for confirmation. Analysis of relative abundance in relation to soil physico-chemical properties and floristic diversity (for host plants) may yield more information on the factors that influence the occurrence of these pathogens. The high variance within the other LUTs however suggests the influence of other factors on *Pythium* incidence at the points. Further investigations are needed to explain these findings.

The relative abundance of *Pseudomonas* as determined from the number of colony forming units decreased with an increase in land use intensity for both pathogenic (fluorescent) and non-pathogenic (non-fluorescent) strains. Forest systems had much higher numbers than the multiple crop, agroforestry and crop monoculture systems. This could be related to the increasing acidity in soils of these more intensively used LUTs. Similar trends in incidence for both pathogenic and non-pathogenic strains show that the two groups are able to co-exist.

In Kenya, long term monocropping and land intensification in terms of frequent application of inorganic fertilizers and herbicides greatly affects the population of *Trichoderma* spp. The use of organic soil amendments results in a soil that has higher amounts of the fungus. Land use system and type of fertilizer used influenced the distribution and abundance of *Trichoderma*. Populations of this fungus in soil with a history of organic production practices were higher than in soils under conventional production practices. Less disturbed soils of the forests also recorded high carbon levels which together favoured the occurrence of the fingus. *Trichoderma* also seemed to favour plants with widely spread rooting systems. Above ground plant type influenced the occurrence of the fungus with annual plants being favoured compared to mono-cropped old plants, indicating that the age of the plant cover also determined the below-ground populations of *Trichoderma* spp. There was evidence that agricultural practices affected the diversity of *Pythium* species in Embu benchmark area of Kenya. Interestingly, napier grass had the highest number of species while maize has the lowest in Embu, while in Taita, natural forest had the lowest and cropland the highest. In Indonesia, it was concluded that diversity and abundance of plant pathogenic fungi were affected by land use types. In Sumberjaya, Lampung, there was a tendency that the more intensive the land is, the more abundant were the soil-borne plant pathogenic fungi.

Mesofauna

In Brazil, the highest density of soil mesofauna was recorded in pasture fields, while diversity was highest in secondary forests (“capoeiras”). The taxonomic assemblages that dominated the soil mesofauna in Brazil were the Formicidae, the Oribatida (Acari) and the Collembola. In India: among the microarthropods studied, mites were the most abundant. Natural forests and tree based systems showed mites in very high numbers indicating that a lot of grazing occurs in these land use systems which might be due to availability of fungi and bacteria in soil and litter. Also recorded was a high micro-arthropod population in agricultural fields in spite of low litter in agriculture. This could be due to better food quality and micro-environmental conditions suitable for the group and aggregated distribution around litter patches. Though litter mass in vegetated sites was high, microarthropods aboundance in per unit of litter were less because huge amount of litter favoured scattered activity and decreased aggregation. Interestingly abundance of mites was much greater in soil than in litter. The abundance of collembolan was high in the soil of cultivated lands. Soil contained a greater amount of microarthropods as a whole than litter.

In Indonesia, collembola community number and diversity increased from undisturbed forests to agricultural land. Abundance of soil surface dwelling Collembola were affected by factors such as a stability of soil surface, low disturbance, and small variability of environmental changes. Thickness and humidity of litter on the forest floor may also have influenced the abundance of surface dwelling Collembola species. The highest abundance of soil surface Collembola such as Hypogastruridae and Entomobryidae were found in undisturbed and secondary forests. It seemed that in undisturbed forests, Collembola were more active on the soil surface than lower in deeper soil layers. Undisturbed forests were dominated by surface crawling and less moving Collembola of the family Hypogastruridae. The thickness of humid litter in the forest floor was very favourable to Hypogastruridae. Morphological characters of Entomobryidae such as long antenna, long spring organ and active mobility was suitable at less dense surface soil and thin litter layer. During our research, the family of Entombryidae was found dominant at shrubs, polyculture and monoculture coffee due to more open and thinner litter layers that were more suitable for them.

Nematodes

In Brazil, it was possible to use data from the nematode community to distinguish among the land use systems. In Côte d'Ivoire, forest conversion into agricultural land significantly altered nematode assemblages, and community structure that are characterized by a reduction of diversity in most of degraded area. Moreover, this study revealed the potential of *Xiphinema* sp. and *Rotylenchulus* sp. to be used as bio-indicators of forest conservation. In Indonesia, a total of 113 nematode genera in seven orders were collected from Sumberjaya, Lampung. There was no significant relationship between increasing land use intensity and the population of soil nematodes. Number of genera tended to decrease as land use intensity increased. The bacteriovores were mostly found in undisturbed forests and disturbed forests, whereas plant feeder nematodes were mostly found in more intensive land uses, i.e. grassland or shrub, food crops and vegetable crops.

In Kenya, it was revealed that nematode diversity decreased with intensity of land cultivation or human interference. The natural forests had the highest diversity and abundance of nematodes of different trophic levels. Natural forest ecosystems are characterized by long-term lack of human interference including lack of application of agrochemicals. Disturbance of the natural forest through felling of indigenous trees, followed by establishment of single species plantations resulted in a decline in nematode abundance and species richness. An increase in the proportion of plant parasitic nematodes (herbivores) was associated with increase in ecosystem disturbance. The trend denotes increased dominance of herbivorous nematodes with increase in agricultural intensification. These changes in nematode community structure could be indicative of wide ranging changes in physical, chemical and biological properties of the soil. Nematode abundance was higher in the maize/bean land use compared to monocultures under coffee, napier or tea. High inputs of agrochemicals particularly pesticides in coffee and fertilizers in tea can be the main contributing factors. In addition, monocultures tend to favour certain groups of nematodes while the others are rendered homeless. In Mexico, it was observed that agricultural management practices affect nematodes. The results suggest that in non-disturbed areas like jungle and agroforesty, richness and diversity of nematodes were significantly higher than in systems under anthropogenic activity and practices like intensive monocropping (pasture field).

Fruit flies (Diptera: Tephritidae)

Fruit flies were only studied in Brazil. Correspondence analysis suggested that there was a direct relationship between the diversity of potential host plant species available to fruit flies in different land-use systems and the diversity of *Anastrepha* flies occurring in them. The values of species richness (S=23) and Margalef's index (3.43) recorded for the upper Solimões River region were both relatively high when compared with other regions of Brazil.

Twenty-one species of the genus *Anastrepha* were recorded in the upper Solimões River region; nine of them were morphotypes. *A. striata* was the most frequent, constant, and dominant species in the upper Solimões River region, representing about 50% of the total number of females collected. Five different land-use systems typical of the upper Solimões River region had the genus *Anastrepha* occurring in each one of them.

Influence of soil fertility on the rhizobial competitiveness for nodulation of *Acacia senegal* and *Acacia nilotica* provenances in nursery and field conditions

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INRA, Dijon Cedex, France; TSBF-CIAT, Kenya

Within the framework of our study, we assessed the nodule occupancy of a mixture of various strains of rhizobia to inoculate several provenances of *Acacia senegal* and *Acacia nilotica*. The first part of the experiment was carried out under greenhouse conditions where the plants were cultivated in polyvinyl chloride tubes containing an unsterilized Sangalkam soil low in organic matter and nitrogen. The results showed that 4 and 8 months after sowing, rhizobial strains CIRADF 306 and CIRADF 300 were mainly present in nodules of *A. nilotica* and *A. senegal*, respectively. After transferring the seedlings to the more fertile soil in Bel Air field station, the molecular analysis of the nodules showed that strain CIRADF 306 was absent from the nodules of *A. nilotica*, whereas strain CIRADF 305 which occurred only at low nodule occupancy in the nursery, predominated in the field conditions. On the other hand, strain CIRADF 300 occurred in the majority of the nodules from the various provenances of *A. senegal*. These results demonstrated actual interaction between inoculated rhizobial strains, soil type and host plant genotype in terms of competitiveness, nodulation and symbiotic nitrogen fixation.

Output target 2007

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

Published work

Barrios[1], E., Delve[2], R.J., Bekunda[3], M., Mowo[4], J., Agunda[5], J., Ramisch[6], J., Trejo[7], M.T. and Thomas[1], R.J. (2006) Indicators of Soil Quality: A South-South development of a methodological guide for linking local and technical knowledge. Geoderma 135: 248-259.
[1]TSBF-CIAT, Cali, Colombia; [2]TSBF-CIAT, Kampala, Uganda; [3]Makerere University, Kampala, Uganda; [4]Africa Highlands Initiative, Lushoto, Tanzania; [5]CARE, Homa Bay, Kenya; [6]TSBF-CIAT, Nairobi, Kenya; [7]TSBF-CIAT, Tegucigalpa, Honduras
Abstract: The increasing attention paid to local soil knowledge results from a greater recognition that farmer knowledge can offer many insights into the sustainable management of tropical soils and that integration of local and technical knowledge systems helps extension workers and scientists work more closely with farmers. A participatory approach and a methodological guide were developed to identify and classify local indicators of soil quality and relate them to technical soil parameters, and thus develop a common language between farmers, extension workers and scientists. This methodological guide was initially developed and used in Latin America and the Caribbean-LAC (Honduras, Nicaragua, Colombia, Peru, Venezuela, Dominican Republic), and was later improved during adaptation and use in Eastern Africa (Uganda, Tanzania, Kenya, Ethiopia) through a South-South exchange of expertise and experiences. The aim of the methodological guide is to constitute an initial step in the empowering of local communities to develop a local soil quality monitoring and decision-making system for better management of soil resources. This approach uses consensus building to develop practical solutions to soil management constraints, as well as to monitor the impact of soil management strategies implemented to address these constraints. The particular focus on local and technical indicators of agroecosystem change is useful for providing farmers with early warnings about unobservable changes in soil properties before they lead to more serious and visible forms of soil degradation. The methodological approach presented here constitutes one tool to incorporate local demands and perceptions of soil management constraints as an essential input to relevant research for development activities. The participatory process followed was effective in facilitating farmer consensus, for example, about which soil related constraints were most important and what potential soil management options could be used. Development of local capacities for consensus building constitute 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 scales.

Tscherning[1,2,3], K., Lascano[1], C., Barrios[2], E., Schultze-Kraft[3], R. and Peters[1], M. (2006) The effect of mixing prunings of two tropical shrub legumes (*Calliandra houstoniana* and *Indigofera zollingeriana*) with contrasting quality on N release in the soil and apparent N degradation in the rumen. Plant and Soil 280: 357-368
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Abstract: Lack of synchronization between N released from prunings applied to the soil as green manures and crop uptake as well as optimization of protein digestibility for ruminants, remain major research objectives for the selection of multipurpose tree and shrub legumes (MPT) for mixed smallholder systems in the tropics. Prunings of the high tannin, low quality MPT *Calliandra houstoniana* CIAT 20400 (Calliandra) and the tannin free, high quality MPT *Indigofera zollingeriana* (Indigofera) were mixed in the proportions 100:0, 75:25, 50:50, 25:75, and 0:100 (w/w) in order to measure the aerobic rate and extent of N release in a leaching tube experiment, and the anaerobic extent of N degradation in an *in-vitro* gas production experiment. Parameters measured in Calliandra:Indigofera mixtures were compared to theoretical values derived from single species plant material (i.e. 100:0 and 0:100). Aerobic N release and

apparent anaerobic N degradation increased with increasing proportion of the high quality legume (Indigofera) in the mixture. While N release in the soil was lower than theoretical values in the mixture 50% Calliandra / 50% Indigofera, this was not the case with apparent anaerobic N degradation with the same mixture. Aerobic N immobilization was more pronounced for the mixture 75% Calliandra / 25% Indigofera than for 100% Calliandra and negative interaction was observed with apparent anaerobic N degradation in the mixture 75% Calliandra / 25% Indigofera. Plant quality parameters that best correlated with aerobic N condensed tannin release and apparent anaerobic N degradation in the rumen were lignin + bound condensed tannins ($r = -0.95$ and -0.95 respectively, $p<0.001$). In addition, a positive correlation ($r = 0.89$, $p<0.001$) was found between aerobic N release in the leaching tube experiment and apparent N degradation in the *in vitro* anaerobic gas production experiment. Results show that mixing prunings of MPT materials with contrasting quality is an effective way to modify aerobic N release pattern as well as apparent anaerobic N degradation and could possibly be applied to minimize N losses in the rumen and in the soil. In addition, apparent anaerobic N degradation was identified as good predictor of aerobic N release in the soil, which has resource saving implications when screening MTP to be used as green manures.

Completed work

Effects of transgenic cotton (Bollgard® Bt Cry1Ac) on plant residue decomposition

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Very high economic losses have been experienced in cotton producing areas of Colombia due to the high incidence of pests. Greatest losses in the cotton planting areas of Colombia were caused by the boll weevil *Anthonomus grandis* (Coleoptera), *Heliothis virescens* (Lepidoptera) and the leaf-eating pink worm *Sacadodes pyralis* (Lepidoptera) and white flies (Homoptera). The use of agrochemicals has been the preferred method of pest control (largely for lepidopterans) in Colombia with mean number of pesticide applications per crop cycle ranging from 26 in the Atlantic Coast to 7 in the Cauca Valley. In 2001, first studies by ICA and the CTN were conducted to determine the effect of the Bollgard technology on cotton pests in the Atlantic Coast (Cordoba Department). The Bollgard technology, generated by Monsanto, has the Cry1Ac insert whose targets are important Lepidoptera cotton pests. Based on results obtained in the 2001-2002 growing cycle, ICA authorized the first commercial planting of cotton with resistance to lepidopterans. The first 6187 ha of commercial GM cotton was planted in the Cordoba department in the second semester of 2003. During the first semester of 2004, 4495 ha were planted in Tolima-Huila and 696 ha in the Cauca Valley where our studies were conducted.

Cotton plant material was collected in September 2004 at the end of the cropping season. Aboveground biomass (tops = stems+leaves+sexual structures) and below ground biomass (roots) were air dried and cut into 10 cm pieces and twenty grams (20 g) were placed separaretly in litterbags. These bags with tops or roots were either placed on the surface or incorporated in the soil (10 cm). A total of 1728 bags were distributed in the field under two treatments (Bt-cotton, NoBt-cotton), 6 samplings per year during a 3 year litter decomposition experiment. Bt cotton residues showed small but significantly less decomposition han NoBt cotton only at the 8 and 12 weeks samplings. These results suggest that Bt plant materials may decompose more slowly than Non-Bt plant materials as shown elsewhere in the literature. The persistence of undecomposed Bt cotton could be a significant Bt toxin reservoir in cotton fields after the harvest of Bt cotton.

Differences in decomposition rates as affected by plant residue type (tops vs. roots) and residue placement (surface vs. incorporated) were significant (Figure 20). Tops consistently presented higher decomposition rates than root materials independently of mode of application. This is likely a result of differences in tissue quality as it has been shown in the literature that shoot tissues with lower C/N ratios are usually of

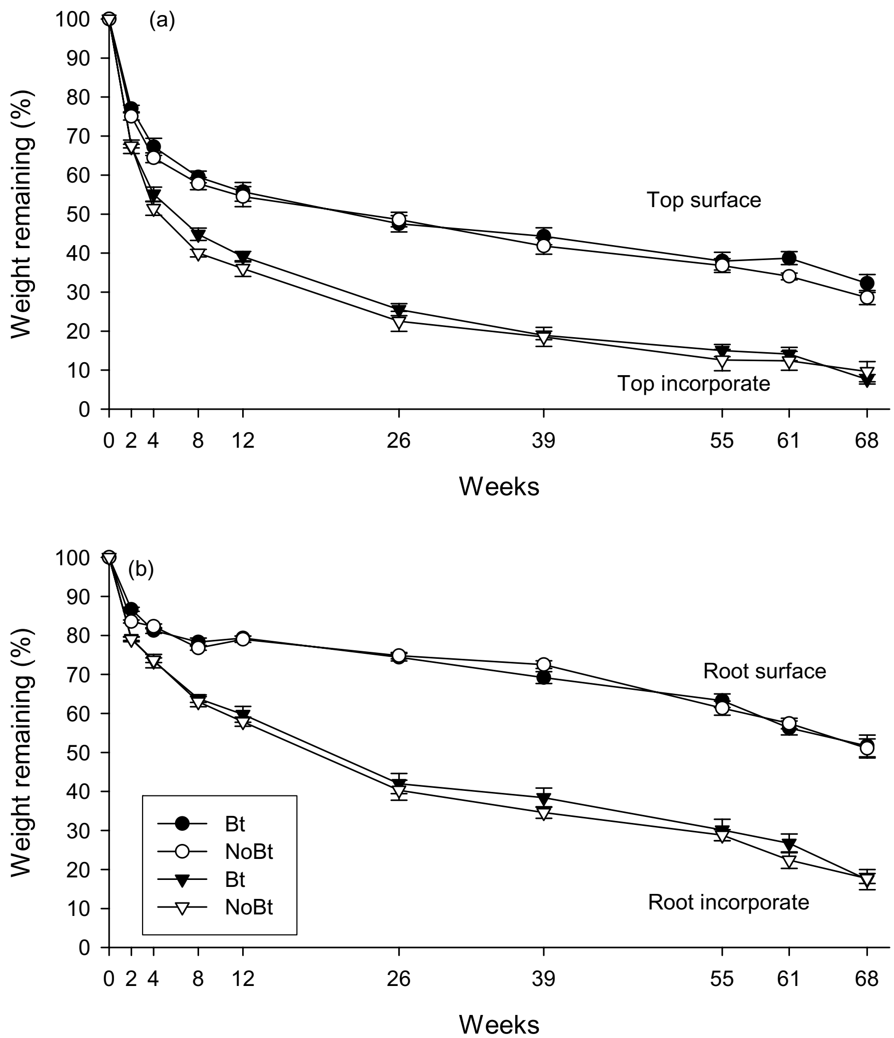

Figure 20. Decomposition of Bt and NoBt cotton tops and roots (expressed as percent of dry weigh remaining) that were surface applied or incorporated into the soil. Bars = standard errors.

the higher quality, and thus decompose faster, than roots. On the other hand, surface applied residues decomposed about 25% less rapidly than when they were incorporated into the soil and differences were significant at all sampling dates. These results are consistent with the literature suggesting that conditions present in the soil facilitate decomposition processes independently of resource quality.

Detritivore arthropods. Soil detritivore arthropods were extracted from litterbags using modified Tullgren funnels and collected into 70% alcohol after each litterbag collection and were recently enumerated and classified. Data are currently being analyzed.

Output target 2008

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

Published work

Chen[1], W.M., James[2], E.K., Coenye[3], T., Chou[4], J.H., Barrios[5], E., de Faria[6], S.M., Elliot[2], G.N., Sheu[7], S.Y., Sprent[2], J.I. and Vandamme[3], P. (2006) *Burkholderia mimosarum* sp. Nov., isolated from root nodules of *Mimosa* spp. From Taiwan and South America. International Journal of Systematic and Evolutionary Microbiology 56: 1847-1851.
[1]Department of Seafood Science, National Kaohsiung Marine University, Taiwan; [2]University of Dundee, Dundee; [3]Universiteit Gent, Belgium; [4]National Chung University, Taiwan, [5]TSBF-CIAT, Cali, Colombia;; [6]EMBRAPA, Brazil; [7]Department of Marine Biotechnology, National Kaohsiung Marine University, Taiwan
Abstract: Fourteen strains were isolated from nitrogen-fixing nodules on the roots of plants of the genus *Mimosa* growing in Taiwan, Brazil and Venezuela. On the basis of 16S rRNA gene sequence similarities, all of the strains were previously shown to be closely related to each other and to belong to the genus *Burkholderia*. A polyphasic approach, including DNA-DNA reassociation, whole-cell protein analysis, fatty acid methyl-ester analysis and extensive biochemical characterization, were used to clarify the taxonomic position of these strains: all 14 strains were classified as representing a novel species, for which the name *Burkholderia mimosarum* sp. nov. is proposed. The type strain PAS44^T (= LMG 23256^T = BCRC 17516^T), was isolated from *Mimosa pigra* nodules in Taiwan.

Velasquez[1], E., Pelosi[2], C., Brunet[3], D., Grimaldi[1], M., Martins[4], M., Rendeiro[4], A.C., Barrios[5], E. and Lavelle[1], P. (2007) This ped is my ped: Visual separation and near infra-red spectra allow determination of the origins of soil aggregates. Pedobiologia 51: 75-87
[1]UMR 137 BIOSOL, Univ. Pierre et Marie Curie (Paris VI), Centre IRD, France; [2]INRA, Grignon, France; [3]UR SEQ BIO, IRD, Montpellier, France; [4]Museu Paraense Emilio Goeldi,Belem, Para, Brazil; [5]TSBF-CIAT, Cali, Colombia.
Abstract: Macroaggregation is a highly dynamic attribute of soils that is claimed to have a significant impact on their ability to store C and conserve nutrients. A major obstacle to the description and modeling of macroaggregate dynamics, and of the associated processes, is an almost complete ignorance of the real origin of the different types of aggregates found in soils, their turnover times and positions in the soil matrix. We present here a general methodological approach in which the origin of aggregates separated according to visual criteria could be determined by comparing their specific organic matter signatures assessed by Near Infrared Spectrometry (NIRS) to signatures of biogenic structures produced by soil ecosystem engineers (invertebrates and roots) living in the same soil. Macroaggregates and other soil components were separated visually from samples taken at 61 locations regularly distributed across a watershed in Nicaragua and representing crops, pastures, forests, coffee plantations and fallows. Coinertia analyses among soil macroinvertebrate communities and the matrix of soil morphological variables showed highly significant relationships. In Amazonian forest patches and pastures from the state of Pará in Brazil, 75 different types of biogenic structures were collected at the soil surface and on tree trunks, and analyzed by the NIRS spectral method. Significant differences among the different types of structures allowed grouping according to their broad phylogenetic origin with large interspecific differences. In a field experiment conducted at the same site, soils previously under pastures were planted in 16 possible combinations of four plant species, in a fully randomized design replicated three times in different sites. Surface casts of the earthworm species *Andiodrilus pachoensis* and soil macroaggrgates separated by our visual technique had significantly different spectral signatures depending on the location of the plot and the composition of plant cover. However, the comparison of NIRS signatures of soil macroaggregates and casts suggested that *A. pachoensis* was not responsible for the production of the biogenic aggregates that comprised a large proportion of the soil volume in this soil.

Work in progress

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

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A single *Striga hermontica* plant can produce as many as 50,000 seeds and remain viable for more than 14 years. Conditioned *Striga* seeds will only germinate when exposed to synthetic germination stimulant or natural stimulants present normally in the root exudates of many hosts or non-host species. Once germinated, the *Striga* seedling must attach to a host root within 3-5 days or the seedling dies. Hence a sustainable control option to reduce *Striga* parasitism is the use of trap crops, particularly legumes that stimulate germination of the parasite seeds but are non-hosts in rotation or intercropping with cereals. Since the ability of leguminous trap crops to stimulate *Striga* seed germination, both between and within species, is variable, the objective of this study was to identify and select in vitro soybean accessions with high ability to stimulate germination of *Striga* seeds.

Roots from thirty-two soybean accessions were tested in laboratory for their ability to stimulate *Striga* seed germination. Seeds treated with strigol displayed high germination, which was not significantly different from stimulation due to soybean accessions like TGX1448-2E and TGX1740-2F. Soybean accessions were significantly different in their ability to stimulate *Striga* seed germination with some soybean accessions showing a higher germination potential than *Desmodium* and *Mucuna*. Maize variety WH502 was slightly more sensitive, causing higher germination of *Striga* seeds compared to the other maize varieties. To confirm above observations, a selection of soybean varieties with differing *Striga* suicidal germination potential was grown in greenhouse pots with soils inoculated with *Striga* seeds (7500 viable seeds per pot) together with or in rotation with maize. *Desmodium* and *Mucuna* were also included, together with a pot with non-infested soil.

In the intercropping trial, most soybean varieties with high suicidal germination potential (except for 2 varieties) showed larger *Striga* germination values than the maize mono-cropped pot, while those varieties with low to medium suicidal germination potential showed *Striga* germination data not larger than the maize monocropped pot (except for one variety) (Figure 21). In the rotational pot trial, half of the soybean varieties with high suicidal germination potential showed larger germination percentages of *Striga* seeds in Eplee bags than the maize mono-cropped pot while those varieties with low to medium suicidal germination potential showed *Striga* germination percentages that were smaller than those in the maize mono-cropped (Figure 22).

The preliminary results of these pot trials clearly confirm some of the trends observed in the laboratory Petri-dish tests and confirm the existence of large variation in suicidal germination potential of different soybean varieties. To confirm above results from the laboratory and greenhouse trials and demonstrate that the best-bet varieties also trigger suicidal *Striga* germination under field conditions, a field trial was set up during the long rainy season of 2006 in Mbita using the best-bet soybean varieties and *Mucuna* in order to follow the *Striga* seedbank depletion under field conditions.

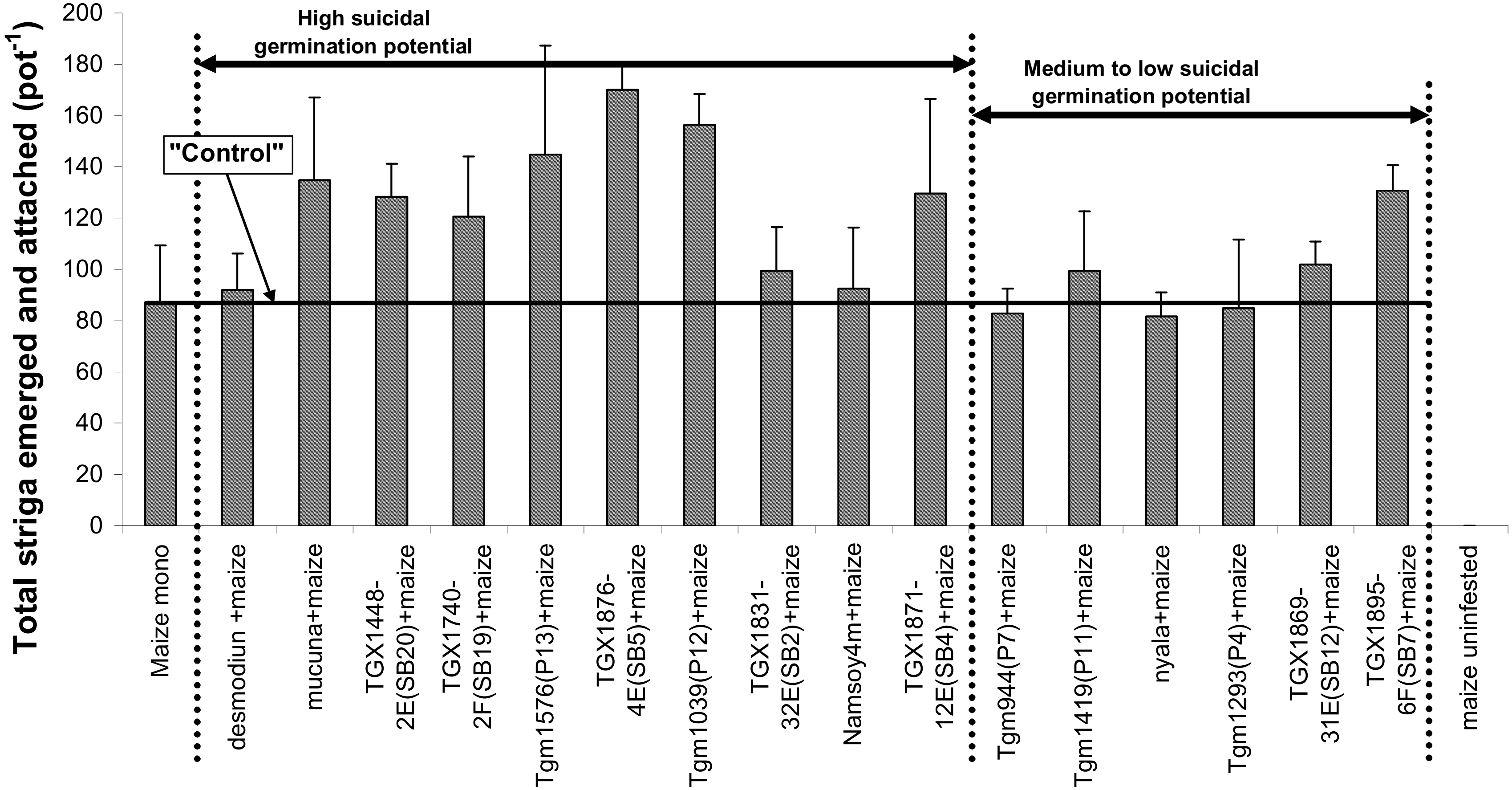

Figure 21. Total Striga seeds emerged and attached to maize in a greenhouse intercropping trial with different soybean accessions with high, medium, and low Striga suicidal germination potential as observed in Table 5 and with Desmodium and Mucuna, relative to a maize mono-crop (indicated with "Control"). The pots were artificially infested with viable Striga seeds, except for one pot ('maize uninfested'). Error bars are Standard Deviations (n=3).

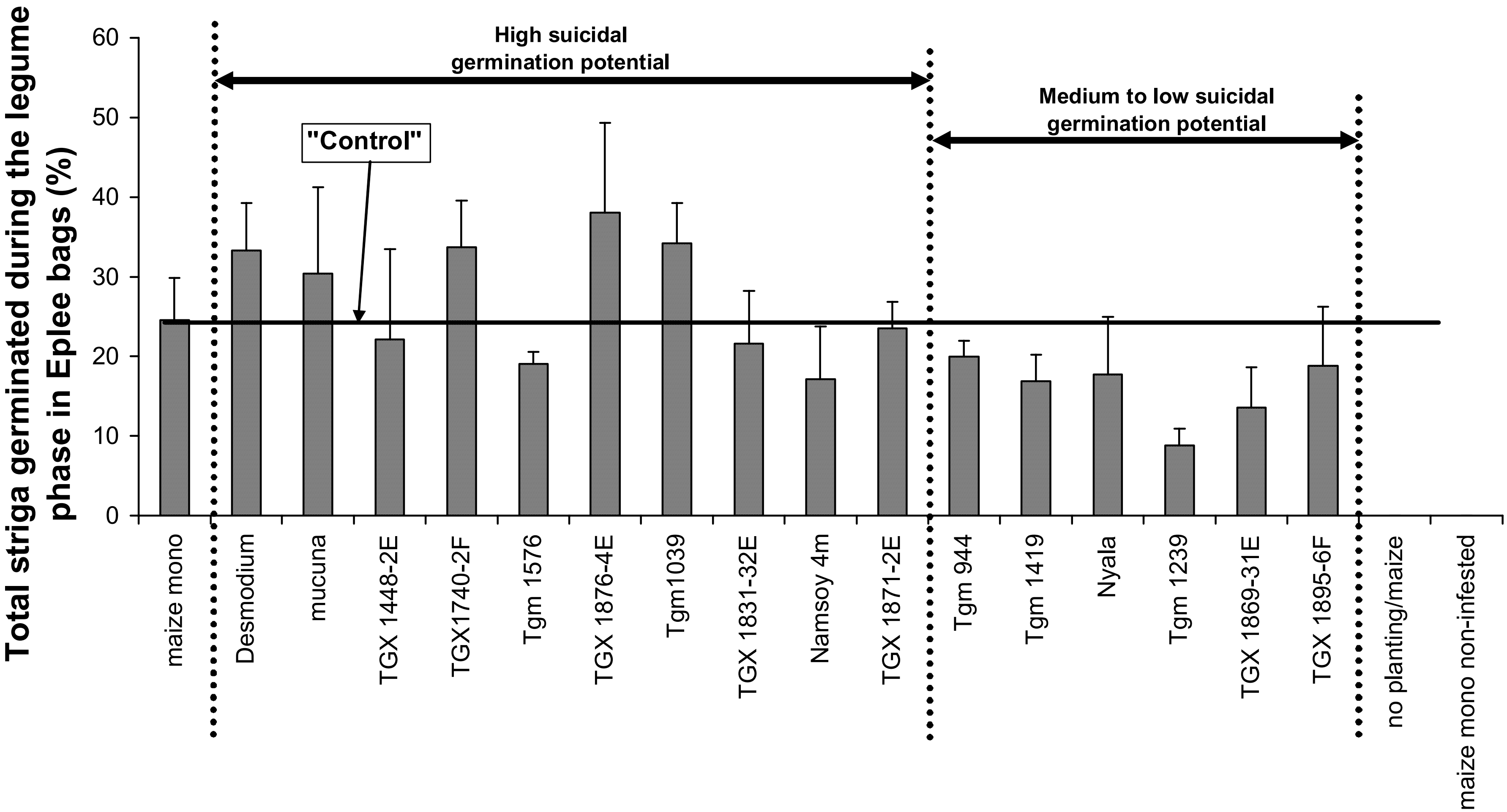

Figure 22. Total Striga seeds germinated in Eplee bags in greenhouse pots, cropped with different soybean accessions with high, medium, and low Striga suicidal germination potential as observed in Table 5 and with Desmodium and Mucuna, relative to a maize mono-crop (indicated with "Control"). The pots were artificially infested with viable Striga seeds, except for one pot ('maize non-infested'). Error bars are Standard Deviations.

Residual effects of applied phosphorus fertilizer on maize grain yield, P availability and recovery from a long-term trial in Western Kenya

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TSBF-CIAT, Kenya

In western Kenya, declining soil fertility, degradation by erosion and nutrient removal from crop harvests have been reported to be the main cause of low land productivity which has transformed a once highly agricultural productive land to a low production zone. Recent studies in western Kenya involving P fertilization have reported positive response of maize to P additions. Several experiments carried out in western Kenya have recommended the combination of small doses of inorganic with organic fertilizers to improve yields and soil properties. This reports summarizes results of a study which was designed to compare the direct and residual effects of (i) a single application of P fertilizer of various rates, and (ii) Seasonal additional application of inorganic or organic P of small rates on the maize yield, maize P utilization and soil available P. Economic benefits of the P additions were addressed and compared as was the modeling of various P pools.

The study was carried out on a farmers field located in Nyabeda, Siaya district, western Kenya. The climate is sub-humid with an average daily maximum temperature of 21 °C and mean annual precipitation of 1800 mm, with a distinct bimodal pattern. In a number of treatments, P was added as TSP only at the beginning of the first crop at different rates (0, 15, 30, 50, 100, 150 and 250 kg P ha^{-1}). A treatment with initial application of 250 kg P ha^{-1} and seasonal additions of 30 kg P ha^{-1} to maintain a reasonable yield through the study period was introduced. In other treatments, an initial application of P (Triple Super Phosphate, TSP) at 100 kg ha^{-1} was followed by a subsequent seasonal application of P at 7 kg P ha^{-1} as TSP, *Tithonia diversifolia* leaf biomass or cattle manure. A blanket application of N and K at a rate of 100 kg ha^{-1} every season was maintained through out the study period to ensure that the two nutrients were not limiting leaving P as the limiting macro nutrient. Maize was grown as a test crop.

The dry matter yield of grain and stover during the 10 cropping seasons revealed that P rates greatly influence the yield of maize grain, except during the SR 1998 season which was severely affected by low rainfall (Table 15). Phosphorus fertilization increased dry matter in the medium to high rates of P (100 to 250 kg P ha^{-1}). Yields declined most rapidly with time when P was applied at low rates, while decline was below 10% after two years when P was applied at 250 kg P ha^{-1}. Overall, the three treatments receiving moderate seasonal P additions (100P+7P (TSP), 100P+7P (manure) and 100P+7P (Tithonia) gave similar grain yields though repeated application of TSP as 7 Kg P ha^{-1} increased grain yield above the single application of 100 Kg P ha^{-1}. On average, grain yields were high from the 250P+30P (TSP) treatment and significantly different from the other treatments (100P+7P (TSP), 100P+7P (Tithonia) and 100P+7P (manure). Total grain output from the 10 maize crops was 3.1 t ha^{-1} the control treatment (0P) and 20.2, 32.8, 33.0, 32.2 t ha^{-1} where 100P, 100P+7P (manure) and 100P+7P (Tithonia) and 100P+7P (TSP) were applied respectively (Table 15). The residual effect of soluble P fertilizer from TSP on grain yield was considerable but decreased with each season whereas that of 100P+7P (manure) was relatively low but persisted for longer time through out the seasons.

In the unfertilized treatment (0P treatment) the average amount of P extracted by resin was equivalent to 3.1 mg P kg^{-1} soil and was little influenced by fertilizer application at the lower rates (15-50 kg P ha^{-1}) except in the application season (Figure 23). The resin extracted P declined rapidly with one time application of high doses of P (100 and 250 kg P ha^{-1}) from a high of 18.6, 15.2 and 36.9 mg P kg^{-1} in the application season to a low of 5.5, 6.7 and 7.3 mg P kg^{-1} in the 100P, 150P and 250P treatments respectively at the end of the cropping period. In treatments receiving low rates of P, (15P and 50 Kg P ha^{-1}) the decline was steady from 5.6 to 4.3 and 8.2 to 4.9 mg P kg^{-1} in the 15P and 50P treatments respectively. Resin extractable P declined in each successive season due to possible fixation and crop removal. The amount and form of plant material added to the soil could have a significant bearing on the magnitude on the available and residual P pools and hence a significant effect on the residual value of the P fertilizer for maize.

Net benefits derived from application of P fertilizer at different rates were determined from the difference between maize grain value and added cost of production due from fertilizer use. Input cost (stated in USD) for the 10 seasons were lowest where phosphorus was applied at the lowest rates as one time application while for moderate and high P additions the cost increased due to extra cost of transport and application of fertilizers up to three to ten times that of the lowest P rate (Table 16). Added benefits were positive and highest in 250P+30P (TSP) at 7415 USD while the benefits were similar in the 100P + 7P (manure) and 100P + 7P (TSP) at 5340 and 5306 USD respectively. Added costs were highest at 1889 and 1863 USD for 250P+30P (TSP) and 100P + 7P (Tithonia) treatments respectively. The added costs for Tithonia were high due to cutting and transportation and labour required for preparation and incorporation thus the treatment was less attractive than manure treatment.

Net benefits for 100P + 7P (manure) remained comparatively high when compared to treatments with high addition of P. This study suggests that limited supplies of manure can effectively be combined with inorganic sources of P to give increased yields and reduces costs.

The fertilizer rate required to obtain a particular target uptake drastically decreases in course of time due to the residual effect of the previously applied fertilizer. Since initial soil P levels were low (2.4 mg kg^{-1}) and plant uptake is only one possible fate of the mineralized P, the contribution by mineralization to plant available P is small. Given the high amount of P remaining in the soil and the massive decline in grain and stover yield (100<150<250 kg P ha^{-1}) respectively a more efficient management strategy for this soil would be to apply small amount of P to each crop as indicated in the seasonal applications treatments. Use of large doses of P such as 250 P with or without seasonal additions of P may in the long term be expensive to the farmers and thus the cost effectiveness of these large amounts must be compared to the low rates with or without seasonal additions. Preliminary modeling findings indicate that labile pool decreased with cropping period due to net transfer to the stable pool and crop uptake. Data analysis is in progress to quantify the actual sizes of labile and stable pools and possible recommendation of the optimal rate of P for this site.

Table 15. Maize grain and stover yield in t ha^{-1} as affected by different P rates.

Grain	LR1998	SR1998	LR1999	SR1999	LR2000	SR2000	LR2001	SR2001	LR2002	SR2002	Total yield
0P	0.32	0.02	0.48	0.54	0.47	0.16	0.57	0.21	0.15	0.17	3.09
15P	1.68	0.07	0.88	0.94	0.70	0.52	0.94	0.22	0.22	0.18	6.35
30P	2.85	0.15	1.35	1.18	0.86	0.46	0.96	0.31	0.28	0.27	8.67
50P	3.64	0.37	3.48	1.66	1.38	0.75	1.33	0.36	0.44	0.58	13.99
100P	3.95	0.66	4.04	3.27	2.55	1.53	2.18	0.55	0.73	0.76	20.23
150P	5.14	0.73	5.56	4.22	4.18	2.62	3.47	1.30	1.22	1.32	29.75
250P	4.84	1.07	6.38	4.78	4.69	3.49	4.39	1.43	1.72	2.24	35.03
250P+30P (TSP)	6.01	1.34	6.84	5.09	5.91	4.56	5.70	3.02	3.74	4.35	46.55
100P+7P (Manure)	5.19	0.81	5.40	4.05	3.83	2.64	4.41	1.26	2.53	2.67	32.78
100P+7P (Tithonia)	3.50	0.75	5.15	4.21	4.06	2.92	4.91	1.68	2.43	3.40	33.01
100P+7P (TSP)	4.30	0.83	4.26	4.34	4.62	3.13	4.12	1.59	2.21	2.75	32.16
Stover											
0P	1.23	0.96	1.80	1.66	1.16	0.79	1.29	1.22	0.95	0.78	11.83
15P	2.76	1.62	2.26	2.71	1.56	1.53	1.76	1.32	1.30	1.08	17.90
30P	3.53	2.37	2.38	2.74	1.89	1.52	1.56	1.22	1.38	1.19	19.78
50P	3.35	2.99	5.06	3.59	2.29	1.89	2.43	1.58	1.82	1.37	26.38
100P	4.47	3.58	4.74	4.35	3.19	2.66	2.52	2.00	2.07	2.19	31.76
150P	4.75	4.26	5.84	4.84	3.77	4.38	3.81	2.68	2.53	2.78	39.65
250P	4.74	4.51	6.03	6.09	4.77	4.43	3.66	2.89	2.91	3.79	43.83
250P+30P (TSP)	5.26	4.25	7.73	6.70	5.98	6.52	6.27	4.02	4.18	6.22	57.11
100P+7P (Manure)	6.14	5.03	5.94	4.96	3.90	3.53	3.76	3.24	4.16	4.57	45.22
100P+7P (Tithonia)	3.72	4.09	5.77	5.29	4.61	4.13	4.44	2.99	3.82	4.10	42.96
100P+7P (TSP)	4.30	4.50	4.27	5.22	3.64	3.55	4.13	2.79	3.12	4.64	40.17

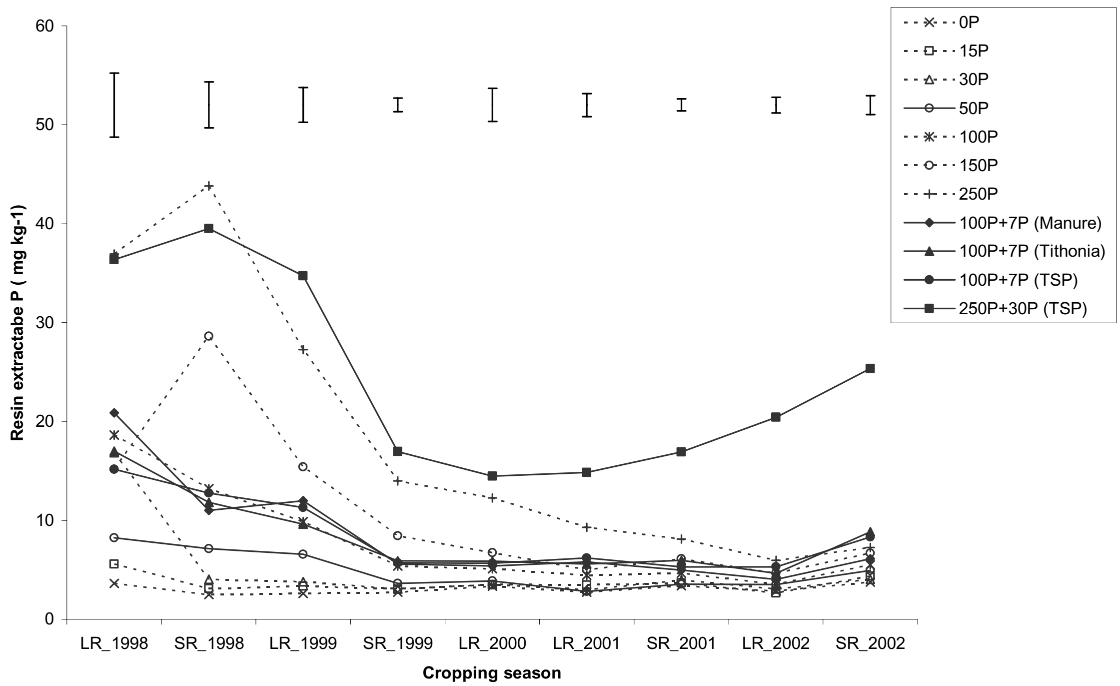

Figure 23. Resin-extractable P as affected by varying rates of P fertilizer during the cropping period considered. Error bars are SEDs.

Table 16. Effects of phosphorus addition on added benefits and cost in USD for 10 successive maize cropping seasons in western Kenya.

P rate	Total added costs over 10 seasons (USD ha^{-1})	Total added benefits over 10 seasons (USD ha^{-1})	Net benefits over 10 seasons (USD ha^{-1})
15P	93	642	549
30P	169	1056	887
50P	312	2065	1753
100P	533	3164	2631
150P	819	4890	4071
250P	1122	5698	4576
100P + 7P (TSP)	891	5306	4415
100P + 7P (Tithonia)	1863	4526	2663
100P + 7P (Manure)	1064	5340	4276
250P + 30P (TSP)	1889	7415	5526

Output target 2008

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

Published work

Kuczak[1], C.N., Fernandes[1], E.C.M., Lehmann[1], J., Rondón[2], M.A. and Luizão[3], F.J. (2006) Inorganic and organic phosphorus pools in earthworm casts (Glossoscolecidae) and a Brazilian rainforest Oxisol. Soil Biology and Biochemistry 38(3): 553-560

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Abstract: We compared differences in soil phosphorus fractions between large earthworm casts (Family Glossoscolecidae) and surrounding soils, i.e., Oxisols in 10 year-old upland agroforestry system (AGR), pasture (PAS), and secondary forest (SEC) in the Central Brazilian Amazon. AGR and PAS both received low-input fertilization and SEC received no fertilization. We found that earthworm casts had higher levels of organic hydroxide P than surrounding soils, whereas fertilization increased organic hydroxide P. Inorganic P was increased by fertilization, and organic P was increased by earthworm gut passage and/or selection of ingested materials, which increased available P (sum of resin and biocarbonate fractions) and moderately available P (sum of hydroxide and dilute acid fractions), and P fertilizer application and land-use increased available P. The use of a modified sequential P fractionations produced fewer differences between earthworm casts and soils than were expected. We suggest the use of a condensed extraction procedure with three fractions (Available P, Moderately Available P, and Resistant P) that provide an ecologically based understanding of the P availability in soil. Earthworm casts were estimated to constitute 41.0, 38.2, and 26 kg ha^{-1} of total available P stocks (sum of resin and bicarbonate fractions) in the agroforestry system, pasture and secondary forest, respectively.

Rondón[1], M., Lehmann[2], J., Ramírez[1], J. and Hurtado[1], M. (2006) Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char additions. Biology and Fertility of Soils. SpringerLink Date of publication online. Friday, November 24, 2006.

[1]TSBF-CIAT, Cali, Colombia; [2]Cornell University, Ithaca, USA

Abstract: The study examines the potential, magnitude, and causes of enhanced biological N_2 fixation (BNF) by common beans (*Phaseolus vulgaris* L.) through bio-char additions (charcoal, biomass-derived black carbon). Bio-char was added at 0, 30, 60 and 90 g kg^{-1} soil, and BNF was determined using the isotope dilution method after adding ^{15}N-enriched ammonium sulfate to a Typic Haplustox cropped to a potentially nodulating bean variety (BAT 477) in comparison to its non-nodulating isoline (BAT 477NN), both inoculated with effective *Rhizobium* strains. The proportion of fixed N increased from 50% without bio-char additions to 72% with 90 g kg^{-1} bio-char added. While total N derived from the atmosphere (NdfA) significantly increased by 49 and 78% with 30 and 60 g kg^{-1} bio-char added to soil, respectively, NdfA decreased to 30% above the control with 90 g kg^{-1} due to low total biomass production and N uptake. The primary reason for the higher BNF with bio-char additions was the greater B and Mo availability, whereas greater K, Ca, and P availability, as well as higher pH and lower N availability and Al saturation, may have contributed to a lesser extent. Enhanced mycorrhizal infections of roots were not found to contribute to better nutrient uptake and BNF. Bean yield increased by 46% and biomass production by 39% over the control at 90 and 60 g kg^{-1} bio-char, respectively. However, biomass production and total N uptake decreased when bio-char applications were increased to 90 g kg^{-1}. Soil N uptake by N-fixing beans decreased by 14, 17, and 50% when 30, 60, and 90 g kg^{-1} bio-char were added to soil, whereas the C/N ratios increased from 16 to 23.7, 28, and 35, respectively. Results demonstrate the potential of bio-char applications to improve N input into agroecosystems while pointing out the need for long-term field studies to better understand the effects of bio-char on BNF.

Completed work

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

M. Quintero[1] and W. Otero[2]

[1] *TSBF-CIAT,* [2] *FUNDESOT, Colombia*

The Fuquene Lake in the Andean region of Colombia has been progressively invaded by aquatic vegetation. Nowadays, about 80% of the original lake surface is entirely covered by these aquatic plants and some of these parts of the lake are fully filled with sediments. Due to the high degree of degradation, the restoration and conservation of this lake has become one of the main objectives for the Colombian environmental authorities since it can affect 27 aquaducts that are supplied by the lake.

During 2005, a research study supported by the Water & Food Challenge Program (WFCP) and the Andean Watershed Project (AWP) of GTZ and CONDESAN, found that by implementing conservation farming practices in the prioritized areas of the Fuquene watershed the negative environmental externalities can be reduced by about 50% while the net income and employment opportunities could be increased. To enhance the adoption of these practices, the project team initiated a financial mechanism to investigate if the suspected restricted financial capacity of small farmers was constraining this technological change in the watershed.

In 2006, the project systematized this experience by describing the entire process, from the research stage to the investment actions. To make this systematization exercise the GTZ provided previously a course to build this capacity in the research team. Subsequently, conservation farming practitioners and traditional farmers were interviewed in order to find out their response to the following questions: what are the main benefits of the mechanisms, what are the constraints for adopting conservation farming, to what extend the farmers are aware of the environmental services they are providing, and what are the difficulties encountered during the process? The entire process is described including the creation of strategic partnerships between research and development organizations, the research activities and its results, and the design, application and benefits of the financial mechanism. In addition, lessons learned were extracted with the aim of providing insights to other organizations interested in designing economic and financial instruments for promoting SLM.

Output target 2009

ü ***Decision tools for soil biota and nutrient management developed and disseminated to stakeholders***

Work in Progress

Improved soybean varieties screened in five locations by farmers in western Kenya: Physical characteristics and grain quality.

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TSBF-CIAT, Kenya

A farmer participatory approach was used to evaluate 12 soybean varieties for their grain quality at full podding in five locations (Oyani, Riana, Kasewe, Akiites, and Mabole) in western Kenya. These comprised of 11 improved varieties (TGx1871-12E, TGx1895-4F, TGx1895-33F, TGx1895-49F, TGX1878-7E, TGx1893-7F, TGx1893-10F, TGx1740-2F, TGx1448-2E, NAMSOY 4m, and MAKSOY 1n) and one local variety (Nyala).

The physical property of the grain is a good indicator of how well the varieties will process. Large, round and same size grains are easier to process than small sized grains. As for the color, yellow to cream colored grains are the preferred ones for processing especially in the large-scale industry. With a yellow-cream colored grain it is easier to process because other colour addition (e.g. spices) from other sources without over-colouring the food product and the more creamy food products are the easier to sell. Most customers buy with their eyes and preference is given to creamy food products.

Grain quality was determined through the analysis of the moisture content, protein, fat and ash for these varieties. Based on their protein content for end use, these varieties were classified into three categories (high, medium, and low protein content). Soybean varieties with protein content of Ó38% were classified as High. These varieties are ideal for home consumption and for fortification purposes (often carried out by industries). The other categories are Medium and Low which could be good for livestock and oil extraction. For oil extraction the higher the oil content (18-20 percent), the better (especially if the protein content is low also). The breeder's material could be of low protein and oil, but varieties must be resistant to pest and/or diseases and subsequently can be crossed for its particular goodness.

The physical properties of the grains were determined by colour, shape and weight of 100 corns. The ideal weight of 100 corns of soybean for industrial use ranges between 18-20 grams. Data processing was carried out using SPSS.

Results of analysis of the eleven TGX varieties compared to local one (e.g. Nyala) based on agronomic treatments showed that three varieties belonged to high protein category. The other varieties belong to medium protein content category. The percentage protein or oil of varieties with the different treatments did not differ significantly from control (pÓ0.05) (Table 17).

The physical characteristics of some the grains showed that most of them had yellow to cream colour, and some immature ones had green colour on the outer coat.

The weight of 100 corns of the grains ranged between 6 and 18 grams. As explained earlier the best 100 corn weight should range between 18-20 grams for industrial use.

Table 17. Comparison of the average percentage protein and oil as per the treatments used within varieties.

Varieties	Percentage protein						Percentage Oil					
	Control	P	P+L	P+L+N	Total	Sig	Control	P	P+L	P+L+N	Total	Sig
Maksoy 1	38	24	32	39	32	NS	18	20	18	18	18	NS
Namsoy 4	35	37	35	40	37	NS	18	19	19	20	19	NS
Nyala	35	34	33	37	35	NS	21	22	21	21	21	NS
SB14	41	38	45	41	41	NS	17	16	16	16	16	**0.05**
SB15	36	32	36	32	34	NS	19	18	19	19	19	NS
SB17	37	39	38	38	38	NS	19	20	19	19	19	NS
SB19	38	38	36	41	38	NS	19	19	18	18	18	NS
SB4	37	36	39	43	38	NS	19	19	18	19	19	NS
SB6	37	40	40	35	38	NS	17	19	19	18	18	NS
SB8	37	35	43	44	40	NS	19	17	17	17	17	NS
SB9	37	36	34.	40	36	NS	19	21	18.	18	19	NS

NS= Not significant
P: Phosphorus; L: Lime; N: Nitrogen

Most of the varieties in this screening exercise were good for home consumption and the local variety (Nyala) and the improved one (Maksoy 4M) were ideal for industrial use. However, the yields from Nyala are generally low and only can be used if the TGX varieties were crossed with them to improve their yield. Thus far the agronomic treatments used in this study had no effect in improving grain size (Table 18). Also, the effect of fertilizer on protein content of the varieties was not as clear and more focus experimentation must be carried out. However, the data collected confirmed that the higher the protein content the lower the oil content (Figure 24).

Table 18. Comparison of mean soybean weight of 100 corns (g) by treatments.

Improved Varieties	Treatments					Significance (Treatments)
	Control	P	P+L	P+L+N	Total	
MakSoy 1n	12	12	13	8	11	NS
NamSoy 4m	17	17	16	18	17	NS
Nyala	14	16	15	16	15	NS
TGX 1878-7E (SB14)	12	10	11	9	10	NS
TGX 1893-7F (SB15)	11	11	12	9	11	NS
TGX 1893-10F (SB17)	11	11	11	12	11	NS
TGX 1740-2F (SB19)	11	11	11	11	11	NS
TGX 1448-2E (SB20)	10	10	10	11	10	NS
TGX 1871-12E (SB4)	9	10	10	10	9	NS
TGX 1895-4F (SB6)	10	8	11	11	10	NS
TGX 1895-33F (SB8)	13	12	12	12	12	NS
TGX 1895-49F (SB9)	10	9	10	11	10	NS

NS=Not significant. Treatments: P= +Phosphorus; P+L= +Phosphorus and Lime; P+L+N= +Phosphorus, Lime and Nitrogen. Control= no treatments.

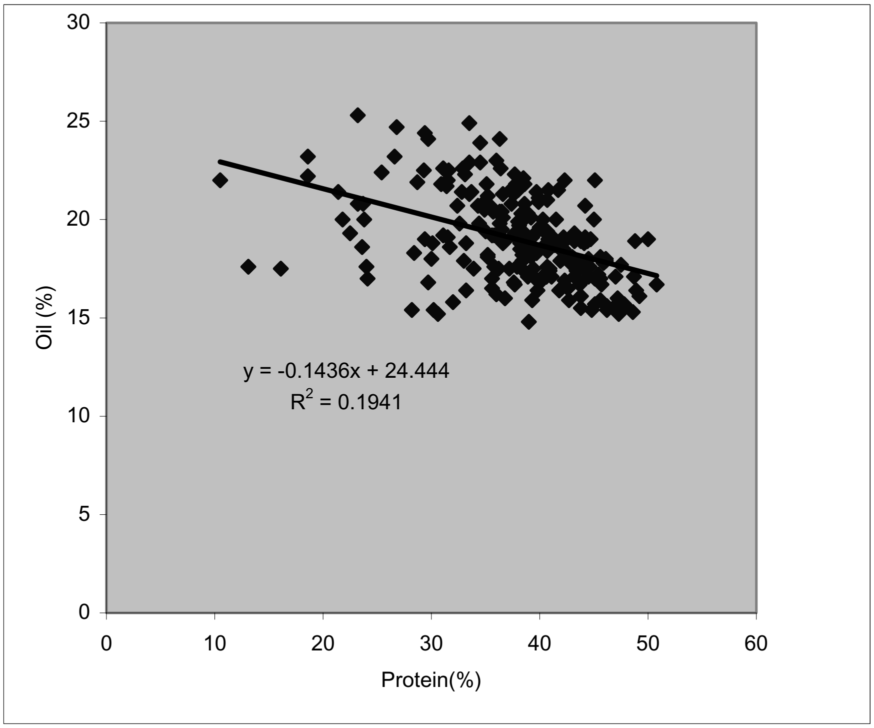

Figure 24. The relationship between percentage protein and oil in soybean grain.

Output target 2009

- ***Knowledge on relationships between soil fertility status and the nutritional quality of bio-fortified crops is used by development partners to target production of these crops***

Progress towards this output target will be reported next year.

Output target 2009

- ***Sufficient knowledge on mechanisms driving tolerance to drought and low soil P is available to guide breeding efforts***

Progress towards this output target will be reported next year.

Progress towards achieving output level outcome

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

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

Development of principles, concepts and methods involve continuous and detailed review of the literature to identify key research questions and research gaps, that are translated into laboratory, greenhouse and field experiments with increasing on-farm research activities. Robust techniques for analyzing heterogeneity of socio-economic and biophysical factors influencing soil fertility management and soil fertility outcomes have now been developed, tested, and applied in a diversity of environments and socio-cultural settings. Research has focused more and more on land management practices, like agroforestry, reduced-till and crop-livestock systems, and their possible impacts of soil fertility and the natural resource base.

Impacts evaluated range from changes in populations of soil microorganisms, changes in soil organic matter, soil P pools and water infiltration, changes in nutrient use efficiency in response to organic and inorganic nutrient sources, to changes in nutrient and resource flows at the farm and village scales in Africa and Latin America. Greater insights have been gained by the careful consideration of the agro-ecological and socio-economic contexts where these land management practices are tested thus increasing our capacity to develop relevant technologies and methods for sustainable land management. The studies into resource allocation on farm and soil fertility gradients within and across farms, are an example. Several studies on fallow management (looking at options for ISFM/nutrient management strategies and the effect on crop performance, fallow management for recovery of soil fertility status, effect of manure application on soil organic matter fractions and soil health status and the like) have greatly contributed to our insight on how such technologies can be applied to improve the natural resource base within the context of the farming system.

Studies into historical land management practices help to identify possible new technologies and practices (e.g. work on bio-char). In many ways these studies, apart from developing principles and concepts, are at the same time a test of technologies developed, like the high fertility trenches technology for hillsides. Investigation of the applicability of conservation agriculture in different systems has confirmed opportunities for introduction of no-till systems on the Colombian savanna Oxisols. Though the basic principles of conservation agriculture are known, their short and long-term effects on the natural resource base, and the applicability to different management systems (in Africa and elsewhere) need to be further investigated.

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

Identification of appropriate indicators of soil quality has remained an elusive exercise because it has been complicated by the need to simultaneously address the multiple dimensions of soil function (i.e. ecosystem services), the many physical, chemical and biological factors controlling biogeochemical processes as well as their variability in space and over time. Intensive work with a large number of farmers groups in various locations in Africa and Central America has documented a diversity of rich, context-specific knowledge, priorities, and constraints of smallholders relating to soil fertility management. An innovative community-based learning strategy has successfully stimulated the growth of a “dynamic expertise” that combines local and outsiders’ soil fertility management knowledge, and may be used elsewhere as a framework for interaction between farmers, scientists and extension workers with a view towards scaling this expertise up and out using local networks and institutions.

Approaches and methodologies to integrate local and scientific indicators of soil quality aim to incorporate local demands and perceptions of soil management constraints as an essential input to relevant research for development activities as well as to empower local communities to develop soil quality monitoring and decision-making systems for better management of the soil resource. Farmers need early warning signals and monitoring tools to help them assess the status of their soil, since by the time degradation is visible and land productivity reduction evident, it is either too late or too costly to reverse it. Furthermore, the costs of preventing reductions in land productivity are often several times less than costs of remedial actions. Conventional approaches to land quality assessment have looked at the physical and/or chemical characteristics of the soil. More recent approaches, however, have included integrative measures like Near Infrared Reflectance Spectrometry (NIRS) and biological measures to assess soil quality. Biological indicators have the potential to provide early warning because they can capture subtle changes in land quality as a result of their integrative nature that simultaneously reflects changes in physical, chemical and biological characteristics of the soil.

Progress towards achieving output level impact

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

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

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