Output 2

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

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Rationale

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

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

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

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

Milestones 2005

No milestones listed in CIAT Medium-Term Plan of 2005-2007

Highlights

- In trials in Western Kenya, aiming at determining limiting nutrients and site-specific responses to applied nutrients for different fields within a farm (soil fertility gradients), clear differences in above two attributes were found between different fields within a farm. This indicates that there is a clear scope for field-specific fertilizer recommendations, provided these are based on local soil knowledge and diagnosis.
- In Western Kenya, the 'push-pull system' was observed to substantially reduce both *Striga* germination and stemborer damage. While herbicide-resistant maize was observed to seriously reduce Striga emergence, resulting in significant response to fertilizer application, maize did not respond to application of fertilizer in the maize mono-crop systems with maize hybrid WH403. In the push-pull systems, application of fertilizer also led to higher Striga emergence but this did not affect the responsiveness of the maize to applied fertilizer.
- In Central Kenya, inoculation with AMF showed considerable potential to enhance the early growth of tissue-culture bananas. Initial observations have also shown significant enhancements in banana growth after application of specific combinations of nutrients as fertilizer.
- Showed that building an arable layer using subsoil tillage and lime + nutrient applications could improve yields of maize by 2 to 3-fold compared with conventional systems of crop production on acid infertile soils of the Llanos of Colombia.
- Preliminary results from the Water and Food Challenge Program funded project on Quesungual system indicated that soil losses under Quesungual Slash Mulch Agroforestry System (QSMAS) of different ages (2, 5 and >10 years) were less than 2 Mg ha^{-1} in 14 weeks in comparison to the 30 t/ha soil losses observed in the slash and burn treatments.

Output target 2006

- ***Decision support framework for ISFM developed, tested with and made available to stakeholders in at least two benchmark countries in Africa***

Published work

D. Lesueur[1] and R. Duponnois[2] (2005) Relations between rhizobial nodulation and root colonization of *Acacia crassicarpa* provenances by an arbuscular mycorrhizal fungus, *Glomus intraradices* Schenk and Smith or an ectomycorrhizal fungus, *Pisolithus tinctorius* Coker & Couch. Annals of Forest Sciences 62: 467-474.

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Abstract. The present study was initiated to (i) determine the ability of an ectomycorrhizal and an arbuscular mycorrhizal symbiont to colonize three provenances of *Acacia crassicarpa* root systems, (ii) to examine plant growth response to the mycorrhizal inoculation and (iii) to measure their influence on the rhizobial symbiosis with a *Bradyrhizobium* isolate. This study has been performed with 2 fungal symbionts: *Glomus intraradices*, an Arbuscular Mycorrhizal fungus, and an ectomycorrhizal fungus *Pisolithus tinctorius* strain GEMAS. Two experiments have been performed during two different climatic periods, hot season (30°C day, 20°C night, June to October) for ectomycorrhizal inoculation and cold season (25°C day, 15°C night, November to March) for endomycorrhizal inoculation. Moreover, *Bradyrhizobium* sp. strain Aus13C has been co-inoculated with each of these fungal symbionts. The results showed that ectomycorrhizal and AM fungal symbiosis clearly benefit to the growth of *A. crassicarpa* provenances and these fungal symbioses greatly improve the rhizobial nodulation process. However, some differences of growth were observed between the provenances tested and our results showed that both Papua New Guinea provenances produced more important total biomass than the provenance from Madagascar in both experiments However, no significant differences were observed in terms of nodulation and mycorrhization. Further research must be undertaken to identify the convenient ecological characteristics in which each kind of mycorrhizal symbiosis exerts the best effect on plant growth and nodulation formation and to identify in such environmental conditions the better rhizobial / mycorrhizal symbiosis combination.

A, Sarr[1], B. Diop[2], R. Peltier[3], M. Neyra[4] and D. Lesueur[5] (2005) Effect of rhizobial inoculation methods and host plant provenances on nodulation and growth of *Acacia senegal* and *Acacia nilotica*. New Forests 29: 75-87.

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Abstract. The purpose of this work was to determine the most efficient methods of inoculation to significantly improve nodulation and growth of *Acacia senegal* and *Acacia nilotica*, grown under greenhouse conditions. Our results showed that inoculation using dissolved alginate beads containing rhizobia significantly improved the growth of both acacias species better than the growth of plants in others treatments. The experiments with *A. nilotica* was done in two unsterilised soils from different areas. Plants grown in soil from Bel Air were well-nodulated and showed better growth than plants grown in soil from Sangalkam. However, no difference between these soils was shown between the several methods of inoculation and their effect on the nodulation and growth of plants. An interaction between *A. senegal* and *A. nilotica* provenances and the effect of inoculation with rhizobia was also demonstrated. Bel Air provenance of *A. senegal*, Dahra and RIM provenances of *A. nilotica* grew best of several provenances tested. These results suggest that (1) it may be possible to improve growth and yield of *A. senegal* and *A. nilotica* by careful selection of each symbiotic partner ; and (2) nursery-grown seedlings of *A. senegal and A. nilotica* should be inoculated, just after sowing, with dissolved alginate beads containing a mixture of selected rhizobia.

Completed work

Strengthening the competitiveness of organic agriculture in Africa through linking farmers to service providers and exporters

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If international and domestic markets continue their projected growth rate, the increasing demand for organic commodities will raise numerous questions about agronomic, economic and social factors that act as barriers to the further development of organic agriculture. Therefore, the future expansion of organic exports not only depends on growing export markets overseas, but on pro-organic research that backs organic growers and traders to produce more of what is demanded from the marketplace. This paper reports on a novel approach of building partnerships between farmers, non-governmental organization, exporters and research to ensure that the increasing organic demand for existing and new export products from the tropics can be realized. Linking demand to the production of organic produce demands a sustained, collective capacity of farmers for generating site-adapted natural resource management strategies and social innovations focusing on improving livelihoods. The project is implemented in two pilot sites in western and central Uganda and central Mozambique. In each site a combination of action research supports farmers in establishing linkages with organic markets. This transition process from traditional to market-led organic production is based on many years experience of implementing the 'Enabling Rural Innovation' (ERI) approach developed by CIAT. Examples from these pilot sites in Uganda and Mozambique will show how this approach has enabled farmers to access new market information (e.g. prices, quantities, quality) and new research products (e.g. disease resistant germplasm, variety evaluation for export, investing in natural resources and soil fertility) on critical aspects of production and how they have used this new information to develop competitive and profitable export organic agroenterprises. Building farmers' capacities to learn about biological and ecological complexity using participatory approaches and involving farmers in experimentation is a critical success strategy for empowering farmers to be able to learn and to innovate. First experiences with the application of the ERI approach to the organic sector will be discussed. Results on farm-level productivity increases, cost-benefit analysis and profitability will be presented and discussed. Capacity building of farmers and their partners in research skills and development activities of individuals for group production and marketing will be presented.

Evaluation of resource management options for smallholder farms using an integrated modelling approach

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Farm-level analysis of trade-offs between soil fertility management alternatives is required to improve understanding of complex biophysical and socio-economic factors influencing decision making in smallholder farming systems and to identify opportunities for improving resource use efficiency. A farm characterization (IMPACT) tool linked to a generic (Household) optimization model was used to evaluate resource use on farms in contrasting wealth categories. The Household model optimized farm's gross margins taking into account productivity of crops and livestock, off-farm activities and food sufficiency. Alternatives for management of nutrient resource were simulated using APSIM for the crop production and RUMINANT for the livestock component. The output from the simulation models was fed into the Household model and evaluated within the biophysical and socio-economic boundaries of the farms. Analysis of the performance a poor farm by IMPACT produced a yearly negative net cash balance of US$ -7, mainly due to negative returns from the cropping system. The farmer relied on donated food and fertilizers. The cash balance was negative, even though she also sold labour to generate income. The net income balance on the poor farm would be increased to US$81 and N balance from 7 kg ha^{-1} to 10 kg ha^{-1} by expanding the area allocated to groundnut from the current 5% to 31%. This would, however, generate a huge demand in labour (46-man days more) and reduce the P balance from 0 to -1 kg ha^{-1}. Maize would be managed more efficiently on the poor farm by cultivating a smaller, well-managed area. A wealthy farm under a maize-dominated cropping system had a net cash balance of US$210, mainly from sell of crop products. Under current resource management, the net cash balance would be increased to US$290 by optimization of diet. The net cash balance for the wealthy farm would be further increased to US$448, and nutrient balances by 271 kg N ha^{-1} and 30 kg P ha^{-1} by expanding the management strategy where maize was grown with a combination of cattle manure and ammonium nitrate. To do this, the farmer would need to source more manure (or improve capture and the efficiency with which nutrients are cycled through manure) and invest in 110 man-days extra labour. Expansion of the area grown to groundnut without fertilizer inputs to a third of the farm reduced net cash balance by US$11 compared to the current crop allocation due to poor groundnut yield. This also increased labour demand by 155 man-days. Groundnut intensification on the wealthy farm would be more economical and labour-effective if a small area is grown with basal fertilizer. Despite reducing nutrient balances for the arable plots, feeding groundnut residues to lactating cows increased net cash balance for the current year through increased milk production.

Target area identification using a GIS approach for the introduction of legume cover crops for soil productivity improvement

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Amidst the economic backdrop of resource-poor farmers, combined research and extension efforts in Uganda have focused on developing and promoting potentially adaptable and economically acceptable agronomic technologies that suit farmers' situations. Practices like improved fallows with woody and herbaceous legumes (e.g. *Canavalia sp., Crotalaria sp., Mucuna sp., Lablab sp.,* and *Tephrosia sp.*) have been considered an appropriate approach to improving soil fertility management and an alternative to expensive inorganic fertilizers. Developing economic and easily adaptable organic matter technologies for resource-poor farmers is one aspect of the research problems but a bigger challenge is how to target such technologies to the most appropriate environmental niches at the farm level, based on the different socio-economic and biophysical conditions within an area. This constraint can be overcome if improved geo-referenced data management systems are used as decision support tools in data compilation and target prioritization to identify sites, through extrapolation from a limited empirical site characterization, to larger area specific target recommendations. Targeting of legume cover crops (LCC) to areas with actual and potential soil fertility management problems using a GIS approach was investigated. Using available datasets it was possible to define, identify, and map potential areas for targeting of LCC soil fertility improvement technologies by overlaying different maps of soil fertility status, cropping systems, population density and climate for the eastern region of Uganda. We show that GIS decision support systems can indeed provide targeted dissemination output to add decision making from a limited number of datasets. Shortcomings in the data are discussed, as are the practical applications of this approach in choosing appropriate legume species.

Output target 2006

- ***Cereal-legumes and livestock systems, with nutrient use efficiency as an entry point, tested and adapted to farmer circumstances in hillsides of Africa***

Completed work

Strengthening "Folk Ecology": Community-based learning for integrated soil fertility management, western Kenya

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Farmers and researchers in western Kenya have used community based learning approaches to jointly developed a "dynamic expertise" of integrated soil fertility management (ISFM). This approach builds on farmers' "folk ecology" and outsiders' knowledge, taking action research on natural resource management beyond methods that are descriptive (ethnopedology) or curriculum-driven (farmer field schools). The paper presents insights from a project's experience of applying the Strengthening "Folk Ecology" approach in western Kenya, with emphasis on the community-based learning process, collective and individual experimentation, the power dynamics of farmer research groups, and learning from the farmer-researcher interface. Farmer groups have been empowered by this approach but diversification into non-soil activities highlights the limitations of experimentation and the challenges of scaling up participatory action research.

Lessons learned (summarised)

1. Experiments must follow local logic
2. Expect different follow-up activities in different sites
3. Successful learning from ISFM empowers diverse group activities
4. Develop a shared language
5. Identify and work with diverse institutions and networks
6. Use formal and informal means to handle elites and disruptive personalities
7. Learn from dissent, silence, and "opting out"
8. Use diverse ways to understand and document "dynamic expertise"
9. Soil ecological knowledge is not universally held or understood

Challenges and opportunities

Knowledge-based models of intervention emphasise the building farmers' understanding of science instead of simply following scientific recommendations (Dilts and Hate, 1996; Röling and van de Fliert, 1994). The SFE approach has also worked hard to have scientists and other outsiders understand and work with "folk ecology" to jointly develop a "dynamic expertise" for soil fertility management. Fundamental questions emerging from the lessons described above concern the further role of experimentation in building "dynamic expertise" and the limits and opportunities for scaling up participatory approaches such as SFE.

Experimentation

While "dialogue" has been central to the joint experimentation and learning within SFE, the project has kept an agnostic attitude towards whether "knowledge integration" as such is itself feasible or even useful. On the one hand, knowledge and opinions about soil fertility management clearly differed greatly within the communities. The heated debates between farmers about indicators, or the varying ways in which married women learn the ecology of their new homes, reflect that diversity. The benefits of bringing complementary knowledge together included identifying relationships and patterns, comparing observations across localities, and helping farmers and outsiders solve problems.

On the other hand, our findings show that locals and outsiders design and test experiments without major methodological differences. This suggests that while knowledge sets are compatible and complementary, we should not expect additional, conceptual "synergies" from farmers and researchers working together. Nevertheless, joint experimentation has created new sites of common experience and shared discovery. By linking new research questions to the emerging dynamic expertise, scientists are able to improve research by focussing on questions of immediate relevance to the farmer research groups (e.g. applying ISFM to under-studied home garden crops, improving composting technologies, providing wider range of multi-purpose legumes for farmer experiments, etc.).

For experimentation to remain important and useful to SFE, there must continue to be a wide range of prototype technologies for farmers to validate, adapt, and refine. For the moment, the emphasis has been on ISFM but the oldest groups (only four years old) are diversifying into activities where the researchers and other project partners have little expertise (e.g. credit, health, and nutrition, etc.). Even within the agronomic experimentation, there is an ever-increasing range of factors to manage (e.g. pest-management options, suitability of crop for climate and intercropping, product marketability, etc.). The capacity of a project team that had formed for one objective (studying the "folk ecology" of soil) is stretched as it moves to embrace ever more objectives, and further stretched if this is to cover yet more groups and sites. If ISFM is indeed destined for a supporting rather than a dominant role in farmer groups' activities, a soil-oriented research institute or project must be ready to accept new roles and responsibilities (and indeed phase itself out of the experimentation process when groups are ready).

Scaling up

The greatest criticism of SFE by scientists and other development practitioners has been that it is perceived as an "anthropological" (i.e. "time-consuming", "complicating rather than simplifying") approach. Farmer groups are indeed experimenting with and applying ISFM concepts, but on the scale of dozens of households, not hundreds or thousands. Impacts appear slowly, distributed unevenly across the social landscape.

One problem lies with the production of "dynamic expertise" itself. To be self-sustaining, this appears to need actors with different but complementary knowledge, new resources, and opportunities. Reducing the role of outsiders and outside knowledge as part of a phasing out process likely also diminishes the flow of new ideas, potentially stagnating the "dynamic expertise". Seeing the enthusiasm of farmer groups for "experimentation" in the project, participating researchers hoped that farmers would then start sharing the experimentation methods behind the new, "dynamic expertise". Instead, most farmer-to-farmer instruction downplayed the experimentation process, focussing instead on presenting "solutions" or "known concepts" that emerged from experimentation. While some of this mirrors the long-standing "transfer of technology" approach familiar to farmers, it is also true that farmers convinced that they have found "best bets" suited to their milieu wanted to share these directly with their friends and relatives and thereby spare them a lengthy experimentation process.

The scaling up of the "dynamic expertise" gained through SFE is not just about disseminating information or even the knowledge behind it, but also about institutionalising new power and confidence to challenge existing structures and assumptions. The potential of groups and social networks to disseminate dynamic expertise or the SFE approach is therefore fundamentally linked to inherent, complex, internal politics and not just the quality of the ideas or technologies. It has become fashionable to suggest that "more" or "better" quality participation can overcome such power structures. However, our experience has shown that groups survived, grew in number, and diversified only in response to the availability of new knowledge, resources, and contacts with outsiders. This finding further reinforces the conclusion that the institutionalisation of the SFE approach in local groups and project partners will take it in multiple directions, subject often to the availability of resources to support the latest activities within the groups' "dynamic expertise". This may appear humbling to soil scientists, but should be a healthy sign, evidence that ISFM can and will be only a subcomponent of improved livelihood strategies.

Nitrogen cycling efficiencies through livestock in African resource-poor mixed farming systems: A review

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Abstract. Success in long-term agricultural production in resource-poor farming systems relies on the efficiency with which nutrients are conserved and recycled. Each transfer of nutrients across the farming system provides a risk of inefficiency, and how much is lost at each step depends on the type of farming system, its management practices and site conditions. The aim of this review was to identify critical steps where efficiency of nitrogen (N) cycling through livestock in smallholder crop–livestock farming systems could be increased, with special emphasis on Africa. Farming systems were conceptualized in four sub-systems through which nutrient transfer takes place: (1) livestock: animals partition dietary intake into growth and milk production, faeces and urine; (2) manure collection and handling: housing and management determine what proportion of the animal excreta may be collected; (3) manure storage: manure can be composted with or without addition of plant materials and (4) soil and crop conversion: a proportion of the N in organic materials applied to soil becomes available, part of which is taken up by plants, of which a further proportion is partitioned into grain N. An exhaustive literature review showed that partial efficiencies have been much more commonly calculated for the first and last steps than for manure handling and storage. Partial N cycling efficiencies were calculated for every sub-system as the ratio of nutrient output to nutrient input. Estimates of partial N cycling efficiency (NCE) for each subsystem ranged from 46 to 121% (livestock), 6 to 99% (manure handling), 30 to 87% (manure storage) and 3 to 76% (soil and crop conversion). Overall N cycling efficiency is the product of the partial efficiencies at each of the steps through which N passes. Direct application of plant materials to soil results in more efficient cycling of N, with fewer losses than from materials fed to livestock. However, livestock provide many other benefits highly valued by farmers, and animal manures can contain large amounts of available N, which increases the immediate crop response. Manures also can contribute to increase (or at least maintain) the soil organic C pool but more quantitative information is needed to assess the actual benefits. Making most efficient use of animal manures depends critically on improving manure handling and storage, and on synchrony of mineralization with crop uptake. Measures to improve manure handling and storage are generally easier to design and implement than measures to improve crop recovery of N, and should receive much greater attention if overall system NCE is to be improved

Enhancing the productivity and sustainability of Integrated Crop-Livestock Systems in the dry savannahs of West Africa

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Traditional farming systems are breaking down as evidenced by shortened fallow periods and expansion of agriculture onto marginal lands. These changes result in lowered productivity and the emergence of unsustainable farming practices with potentially disastrous consequences for poor people, their food security and their environment. Although some technologies are available, they are not adopted by farmers due to high costs and unavailability of inputs. Alternative technologies involving cereals, grain legumes, ruminant livestock and improved agronomic practices in an integrated and holistic manner could be an appropriate response to ameliorating soil fertility, crop yields, feed quantity and quality for livestock. A multi-center, multi-disciplinary approach was implemented using farmer participatory research to understand and address the constraints faced by smallholder crop-livestock farmers in the dry savannas of West and Central Africa. The benefits of working together are at least additive, but synergistic effects are also anticipated. A pilot project was implemented in Kano State, northern Nigeria in 1998 and in 1999 this was expanded to include another site in northern Nigeria as well as sites in Mali and Niger. This paper describes the implementation, evolution and progress of a new approach to improving crop-livestock farming in the dry savannahs whereby best bet packages involving elements of crop varieties, crop geometry, soil fertility, residue and livestock management are assessed on-farm using a holistic strategy including biophysical and socioeconomic monitoring

A critical analysis of challenges and opportunities for soil fertility restoration in Sudano- Sahelian West Africa

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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, rockphosphates 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 modelling 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.

Appropriate available technologies to replenish soil fertility in southern Africa

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In southern Africa, natural fallows which were traditionally used to replenish soil fertility are becoming increasingly rare. The nutrient reserves of the soils are being depleted because of insufficient fertilizer application. The consequent downward spiral of soil fertility has led to a corresponding decline in crop yields, food insecurity, food aid and environmental degradation. The central issue for improving agricultural productivity in southern Africa is how to build up and maintain soil fertility despite the low incomes of smallholder farmers and the increasing land and labour constraints they face. Under this review five main options: inorganic fertilizers, grain legumes animal manures and integrated nutrient management and agroforestry options are available and appropriate to smallholder farmers. Issues to be addressed in the use of inorganic fertilizers are reduction in the costs of fertilizers, increase their timely availability and increase in fertilizer use efficiency and profitability. Legumes can be used to diversify farm system productivity. Further, markets have to be developed for various legume products. Soil fertility on many farms has to be raised especially with P and lime application to support better legume growth and biological nitrogen fixation (BNF). Selecting and breeding legume crops for low soil fertility conditions is also imperative. Manure availability and quality are central issues in application of animal manures by smallholder farmers. Increasing efficiency of manure quality and quantity through proper handling and application methods should be pursued. Farmers will not have adequate amounts of either inorganic or organic inputs. Integrated nutrient management of soil fertility by combined application both inputs will increase use efficiency of inputs and reduce costs and increase profitability. Ways of improving availability of organic inputs on farms will be discussed. Issues such as quality of inputs, nutrient balancing, labour to collect and transport organic inputs and their management need to be optimized. These factors are challenges of adoption and scaling up of these options to millions of smallscale farmers. Factors which will facilitate adoption are, develop wide range of options with farmers, good germplasm delivery systems, sharing of knowledge and information and policy options to favour these practices.

Appropriate available technolologies to replenish soil fertility in Eastern and Central Africa

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Low inherent soil fertility in the highly weathered and leached soils largely accounts for low and unsustained crop yields in most African countries. But in particular, the major nutrients, N and P, are commonly deficient in these soils. This scenario of nutrient depletion is reflected in food deficits and hence the food aid received continuously, particularly in sub-Saharan Africa. Undoubtedly, substantial efforts have been made in the continent to replenish the fertility of degraded soils in attempts to raise crop yields, towards self-sufficiency and export. Such efforts consist of applications of both organic and inorganic nutrient resources to improve the nutrient status of soils. Overall, positive crop responses to these materials have been obtained. Thus in the East African region, maize (staple) yields have been raised from below 0.5 Mg ha^{-1} without nutrient inputs, to 3-5 Mg ha^{-1} from various nutrient amendments at-on-farm level. In this paper, we highlight the impacts of using materials of different characteristics (qualities) in relation to improved crop yields but specifically the phosphate rocks that are widely distributed in Africa. Due to low purchasing power of the smallhold farmers, who constitute over 80% of farming communities, we suggest the production of low cost packages, such as the "PREP-PAC", which target the correction of specific soil fertility problems. PREP-PAC ameliorates the fertility of the worst soil fertility patches common on smallhold farmlands. Economic based information is also given related to the use of various soil fertility management technologies. Above all, the paper underscores the need for side-by-side comparisons of options for soil fertility replenishment. This approach empowers the farmer to observe, rate and choose the promising technologies but pinpointing the economic factors. This appears to be one way forward towards the technology adoption process.

Within-farm soil fertility gradients affect response of maize to fertilizer application in western Kenya

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Different fields within a farm have been observed to have different soil fertility status and this may affect the response of a maize crop to applied N, P, and K fertilizer. A limiting nutrient trial was carried out at six farms each, in three districts of Western Kenya. In each of the farms, the following treatments were laid out in three fields with different soil fertility status at different distances from the homestead (close, mid-distance, remote fields): no inputs, application of NPK, NP, NK, or PK fertilizer (urea, triple super phosphate, KCl) to maize. Total soil N decreased at all sites with distance to the homestead (from 1.30 to 1.06 g kg^{-1}), as did Olsen-P (from 10.5 to 2.3 mg kg^{-1}). Grain yields in the no-input control plots reflected this decrease in soil fertility status with distance to the homestead (from 2.59 to 1.59 Mg ha^{-1}). In the NPK treatments, however, this difference between field types disappeared (from 3.43 to 3.98 Mg ha^{-1}), indicating that N and P are the major limiting nutrients in the target areas. Response to applied N was related to the soil total N content in Aludeka and Shinyalu, but not in Emuhaya, probably related to the high use of partially decomposed organic inputs with limited N availability. Consequently, response to

applied N decreased with distance to the homestead in Aludeka (from 0.95 kg kg^{-1} relative yield to 0.55 kg kg^{-1}) and Shinyalu (from 0.76 kg kg^{-1} to 0.47 kg kg^{-1}), but not in Emuhaia (from 0.75 kg kg^{-1} to 0.68 kg kg^{-1}). Response to applied P was related to the soil Olsen-P content at all sites. While for farms with a relatively high Olsen-P gradient, response to applied P decreased with distance to the homestead (from 0.99 kg kg^{-1} to 0.68 kg kg^{-1}), large variability in Olsen-P gradients across field types among farms within a specific site often masked clear differences in response to P between field types for a specific site. Clear scope for field-specific fertilizer recommendations exists, provided these are based on local soil knowledge and diagnosis. Scenario analysis, using farm-scale modelling tools, could assist in determining optimum allocation strategies of scarcely available fertilizer for maximum fertilizer use efficiency.

Work in progress

Value of farmer-demonstration trials as a community-based knowledge transfer tool: Vegetable fertilization trials

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Food insecurity is a serious challenge facing the social and economic development of Kenya. Soil fertility improvement via fertilizer amendments is a common method used by governments, and research and development organizations to combat food insecurity at the farm level. The objective of this paper is to assess the effectiveness of farmer-demonstration trials (FDTs) as an educational tool for relaying soil fertility technologies, new materials and methodologies, to small-landholder farmers. This will be done by assessing their scientific value. Results showed that the yield and nutrient response of four indigenous vegetables to four treatments were inconsistent. No single treatment increased either particular nutrients or yields in any vegetables. The use of *Tithonia diversifolia* is perhaps the most promising; however, more scientifically rigourous methodologies must first be used, with the aid of community farming groups, before any confident statements can be made on response. The positive response of farmers, in their participation and adoption of technologies showed that FDTs are an effective knowledge transfer tool. Development organizations using FDTs need to ensure that scientific methodologies in experiment design are followed as closely as possible.

Local Logic and Species Selection

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New legume species or any other technology however ‘promising’ should never be recommended for wide-scale application by farmers until it has been rigorously evaluated, especially through participatory processes in the field under realistic conditions. Species screening was undertaken as a tool for interactive learning between farmers and researchers, which stimulated rigorous evaluation of selected new varieties. The overall objective of this exercise was to understand farmers’ and other individuals’ criteria for accepting or rejecting varieties of legumes. This objective was achieved through i) tools of dialogue ii) partnerships with local farmer field schools (FFS) and farmer research groups (RGs) for a period of two years to manage screening plots and iii) systematic visits to screening plots for participatory evaluations. Evaluations were carried out i) by farmers filling in collectively designed ‘plot performance forms’ ii) through focus group discussions iii) through in-depth interviews and iv) by holding soybean utilisation field days. Results showed that the most important underlying criteria for preference of new species were based on sustainability. Sustainability was determined by key aspects of local logic: tolerance to low rainfall, high maturity rate, higher harvest and resistance to pests and diseases. Preferences derived from differentiation between species on the basis of cost of production, seed longevity and price differences on local produce markets were yet to be discerned well by farmers. These three factors take longer to be appreciated.

‘Opting out’: Explaining rejection of soil fertility research and knowledge among many smallholder farmers of western Kenya

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By embracing participatory research processes and scaling up of integrated soil fertility management (ISFM) and knowledge, many institutions expected significant increase in agricultural production. This has not been the case. This paper therefore is a case study of the rejection of participatory ISFM research and knowledge among selected smallholder farmers of western Kenya. C*ritical case sampling* was used to select cases of ‘opting out’ of the research process. These cases were identified as being particularly notable. Results showed that farmers’ decisions over participation in research and scaling up activities were shaped by factors such as facilitation skills, long-term vs. short-term gains, personality and the local ‘politics of research’, contradictory policies or practices of research institutions and the nature of ISFM technologies researched or disseminated. This paper therefore suggests that researcher-farmer and farmer-farmer partnerships are necessary for longer-term goals. Such partnerships can be achieved if policies and practices of collaborating institutions are harmonised and participatory research objectively guided and reviewed against longer-term objectives.

Effects of cotton-cowpea intercropping on cowpea N_2 fixation capacity, nitrogen balance and yield of a subsequent maize crop under Zimbabwean rain-fed conditions

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Intercropping cotton and cowpea is one of the ways to improve food security and soil fertility while maintaining cash income of the rural poor. A study was carried out to find out the effect of cotton-cowpea intercropping on cowpea N_2-fixation capacity, nitrogen balance and yield of a subsequent maize crop. The treatments for the first season were; sole cotton, sole cowpea, 1 row of cotton alternating with 1 row of cowpea (1:1) and 2 rows of cotton alternating with 1 row of cowpea (2:1) and these intercrops were planted at the same time (simultaneously). The second season treatments were maize sown to the plots that had intercrops with no N fertilizer added and these were compared to three levels of fertilizer application i.e. 0, 30 and 60 kg N ha^{-1}. Results showed that cowpea suppresses cotton yields but the reduction in yield was compensated for by cowpea grain yield of and also the residual fertility from cowpea residues. Intercropping cotton and cowpea increased the biological productivity (as shown by land equivalence ratios which were greater than 1.0 for the intercrop treatments) of the system, increased food security and improved soil quality. Cowpea grain yield was as follows, sole cowpea (1.6 Mg ha^{-1}), 1:1 intercrop (1.1 Mg ha^{-1}), and 2:1 intercrop (0.7 Mg ha^{-1}). Cotton lint yield were, sole cotton (2.5 Mg ha^{-1}), 1:1 intercrop (0.9 Mg ha^{-1}) and 2:1 intercrop (1.5 Mg ha^{-1}). The intercrops were productive as compared to the sole crops with an average land equivalence ratio (LER) of 1.3 for both dry matter and grain yield. There was an increase in N_2-fixation by cowpea in intercrops as compared to sole crops though the amount fixed was lower due to reduced plant population. Sole cowpea had N_2-fixation of 73%, 1:1 intercrop had 85% and 2:1 intercrop had 77% while the total amount derived from N_2-fixation was, sole cowpea (104 kg ha^{-1}), 1:1 intercrop (96 kg ha^{-1}) and 2:1 intercrop (51 kg ha^{-1}) . Sole cowpea and the intercrops all showed positive N balances of 42.5 kg ha^{-1} for sole cowpea, 60.0 kg ha^{-1} for 1:1 intercrop and 25.7 kg ha^{-1} for 2:1 intercrop. Cowpea fixed N transferred to the companion cotton crop was very low with 1:1 intercrop recording 3.5 kg N ha^{-1} and 2:1 intercrop 0.5 kg N ha^{-1}. Maize grain yield was as follows, after sole cotton (1.1 Mg ha^{-1}), sole cowpea (3.0 Mg ha^{-1}), 1:1 intercrops (2.8 Mg ha^{-1}) and 2:1 intercrops (2.5 Mg ha^{-1}). The previous crop residue were beneficial especially from intercrops and sole cowpea than from sole cotton as shown by reduced yields following sole cotton. The LER, yield, %N fixation and, positive N balance and residual fertility shows that cotton-cowpea intercropping is a potentially productive and ecologically sound system that can easily fit into the current smallholder farming systems.

Creating niches for integration of green manures and risk management through growing maize cultivar mixtures in southern Ethiopian Highlands

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Maize yield fluctuation in small scale farms of East Africa is associated mainly to intermittent drought, soil fertility decline and choice of intercrops. On-farm experiments were conducted between 2000 and 2004 in Areka, Southern Ethiopia to evaluate the effect of maize mixtures or pure stands on maize grain yield and the biomass production of vetch (*Vicia dasycarpa*) when grown as an intercrop under fertile or non-fertile farm plots. We used mid-late maturing, A511 (145 days, 2.45m tall) and early maturing, ACV6 (120 days and 2.04m tall) maize varieties and a local vetch . Under sole cropping, the grain yield of mixtures was significantly higher (by 1.5 tha^{-1}) ($P<0.05$) than early variety, cv ACV6, but lower than the late maturing variety, cv A511, across years. Similarly, the grain yield of mixtures was significantly higher than sole cv ACV6 but lower than A511 in fertile plots while ACV6 out yielded both late maturing variety and the mixtures in less fertile plots. Intercropping with vetch did not affect the yield of mixtures while it caused a significant yield decline in A511, by about 35% ($p<0.05$), particularly in years with intermittent drought. On the other hand, vetch biomass was significantly reduced under intercropping with maize, by 94% in A511 but 66% in mixtures. Vetch was more sensitive to low soil fertility than maize. Farmers' evaluation indicated that cultivar mixtures could intensify their systems by leaving space for intercropping, shortening hunger period, minimizing risk of complete crop failure and as a stake. Maize mixtures could be functional niches to integrate green manures and facilitate adoption for soil fertility improvement which other wise were not accepted by farmers for scarifying one season to grow them as fallows.

Increasing efficiency of use of green manure legumes through minimizing trade-offs between soil fertility management and livestock feed

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There is a broad understanding about the importance of legumes as soil fertility restorers, quality livestock feed, pest and disease cycle breakers, improved human nutrition and many other uses. However, integration of legumes in various systems of East African Highlands remained to be elusive as discussed earlier (Amede and Kirkby, 2004; Amede, 2004). In our earlier attempts we showed that various food, feed and green manure legumes have various farm and household niches, but not all options are fitting to all systems. Despite a significant increase in crop yield as an after effect of legume cover crops less than 10% of the farmers were willing to integrate them in to their system due to associated opportunity costs of land, labour and other inputs. Even those farmers who integrated legumes were searching for alternative niches in the farm to minimize competition for production resources with food crops. Some farmers started to grow them at farm borders to use for biomass transfer while others were growing them on low fertile farm corners but remove the above ground biomass for feed. This activity, which started in 2004 in collaboration with the African Soils Network, Afnet, was set to quantify the trade-offs between soil fertility, livestock feed and other uses in Areka, southern Ethiopia. The system is characterized by intensive cropping with a clear soil fertility gradient from the homestead to the outfield. The soils are predominantly nitisols, with high P fixation, Al accumulation and low pH (for details Amede et al., 2001). This year's experiment evaluated the biomass productivity of four various green manure legumes namely Lablab (*Lablab purpureus*), Soy bean (*Glycine max*), Crotalaria (*Crotalaria ochroleuca*) and Vetch (*Vicia dasycarpa*) in the first season. In the second season, these legumes were chopped at late flowering stage and incorporated to the soil in three different ways. In the first case, all biomass was chopped and incorporated in to the same plot where the legume crop was grown, in the second treatment the above ground biomass was removed and only the below ground biomass (roots) are left and the above ground biomass is used as a source of biomass transfer and in the third case the above ground legume biomass, which is produced in a plot was applied in another nearby plot. Three weeks after incorporation a wheat crop was planted in the same season on these various legume treatments, using 100 kg ha^{-1} TSP across treatments. Additional research plots of Urea (50 kg ha^{-1}) and TSP/Urea (150 and 50 kg ha^{-1}) and check (without application of organic or chemical fertilizers) were included for comparison.

Table 16.. After effects of various legumes, when applied as whole biomass or roots only or above ground biomass only, on wheat yield in Areka, Southern Ethiopia, 2005.

Legume source	Legume biomass weight (Mg ha^{-1})	Wheat grain yield (Mg ha^{-1})	SE	Wheat biomass Yield (Mg ha^{-1})	SE	Plant height (cm)	SE
Lablab whole biomass	21.00	7.	0.31	11.43	2.23	88.88	3.72
Lablab above ground	18.25	5.72	0.83	5.75	0.86	71.06	2.85
Lablab roots only	ND	6.23	0.28	6.58	0.82	79.38	2.32
Soya whole biomass	13.38	5.81	0.26	7.67	0.58	80.38	1.67
Soya above ground	14.13	6.07	0.85	6.33	0.24	77.25	3.39
Soya roots only	ND	5.68	0.25	6.08	0.75	80.63	2.13
Crotalaria whole biomass	-	4.25	0.19	5.83	1.97	78.31	3.94
Crotalaria above ground	-	3.03	0.39	3.00	0.14	65.25	1.52
Crotalaria roots only	ND	5.82	0.28	5.33	1.03	73.69	1.83
Vetch whole biomass	4.75	5.82	0.37	7.67	2.83	74.38	7.38
Vetch above ground	5.00	3.56	0.35	4.25	1.31	67.31	4.10
Vetch roots only	ND	4.42	0.48	5.83	1.88	74.63	7.18
Urea		5.54	0.40	5.75	1.01	77.38	3.32
TSP and Urea		7.38	0.47	7.17	1.29	76.31	5.62
Check		3.45	0.22	3.17	0.50	66.56	1.79

Similar to the findings in 2004, wheat yield was affected by the type of the preceding legume, and wheat yield varied with whether all the biomass or only the above ground biomass was incorporated into the soil. The highest grain and biomass yield across treatments was obtained from lablab followed by chemical fertilizers. Wheat yield was higher in the legume fields than the chemical fertilizers. It was also higher when the total biomass was incorporated to the soil than when only the roots or the above ground biomass was incorporated. Grain yield of wheat was also higher when wheat was grown in the legume fields where roots are left than in fields where the above ground biomass was applied as a biomass transfer (Table 16). The population of wheat was lower in fields where total biomass was incorporated than in fields where only roots or only shoots were applied, implying that seed emergency could be reduced under whole biomass incorporation, especially when it is planted after a short period of decomposition. The most important finding of this work was that farmers could grow legumes as a short term fallow, cut the above ground biomass for the animal feed and yet they could get between 30 and 90% yield advantage over the control. In situation where they incorporate the whole biomass in the same plot they yield advantage could be more than 100%, as it was observed in lablab (Table 16). Soil analysis is going to be conducted in early 2005 to finalize the work.

Enhancing the productivity of degraded outfields through increasing farmers capacity and integration of improved practices

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There is a national consensus in Ethiopia among policy makers, environmentalists and development institution that soil erosion has been one of the most chronic problems of the agricultural system, and attracted attention of donors and development institutions to invest on terracing since the 1980s. Besides soil erosion, hundreds of years old exploitive land use aggravated by increased human and livestock population lead to the extraction of natural capital, mainly through farming of sloping lands and overexploitation of slowly renewable resources . The effect is reflected through disruption of biological processes such as loss of biological diversity and vegetative cover, soil loss, nutrient imbalance, decline in soil organic matter, decrease of water retention capacity. The soils in Southern Ethiopian Highlands, Areka, are characterized as Nitosols, highly weathered, and subject to intensive cultivation with out external inputs. Various attempts to integrate land management technologies by a wide range of governmental and non-governmental institutions continues to prove unsuccessful, and soil fertility decline in small scale farms remained to be an intransigent problem. The rural poor in the region are often trapped in this vicious poverty cycle between poor access to resources (poverty), land degradation, and lack of relevant knowledge and/or appropriate technologies to generate adequate income and opportunities to overcome land degradation. As crop/livestock production is the major source of household income, decline in soil fertility, through nutrient depletion and poor soil water holding capacity affected the on-farm income, labour productivity and crop and livestock yield significantly. There is an increasing human population in this region in recent years, which have significantly contributed to land fragmentation and reduced farm size to less than 0.5 ha per family of 7 . Moreover, there is a huge variability in soil fertility status within a farm, whereby the homestead fields are more fertile than the far away outfields due to deliberate allocation of resources in favour of more intensified homestead fields . As a result the productivity of the outfields has been declining over years and is currently in a situation whereby most crops either fail to grow or produce significantly low yield.

An integrated research approach was sought whereby a combination of improved interventions and farmers' innovations has been employed to address land degradation at landscape and farm levels. The major objective of the research were a) to enhance the capacity of farmers to identify the degradation hotspots within their farm and beyond, 2) to identify low cost and easy to use technologies to address soil fertility decline and 3) to evaluate the effects of these interventions on crop yield and soil fertility parameters in the short term.

The research was done in Gununo, Areka district, Southern Ethiopia, which is one of the AHI benchmark sites. The farming system could be characterized by multiple cropping system growing diverse annual and perennial crops including enset and coffee sweet potato, taro, maize, wheat and many others. It is one of the highly populated districts in the country (>400 people km^{-2}), with average land holdings of less than 0.5 ha. At between 1880 and 1960 meters above sea level, this area has mean annual rainfall of about 1300 mm, and an average temperature of 19.5 ^{o}C. Rainfall is bimodal, with a short rainy season (belg) from March to June and the main rainy season extends from July to October, with July August receiving the highest rainfall. The dominant soils in the study area are Eutric Nitisols, very deep (>130 m), P-fixing, acidic in nature, and are characterized by higher concentration of nutrients and organic matter within the top few centimetres of the soil horizon. Following a participatory landscape analysis, fifteen representative farms with clear soil fertility gradients, and where soil fertility decline particularly in the outfield is apparent, were selected. The farmers, in consultation with their family members, identified the most unproductive crop field of their respective systems. We have then conducted a questioner to understand the root causes for soil fertility decline and the land use history of the respective farm units. We have also bookmarked 150 m^2 land area of a research plot in each farm corner to target innovations and improve the productivity of the farm through participatory research and innovation. Vetch was under sown under the potato crop two weeks after planting potato to minimize investments of land and labour and increase biomass production. There were three treatments namely wheat after vetch biomass, wheat after potato biomass and wheat control. The on-farm experiments were conducted by farmers in close consultation with researchers. Each farm is considered as a replicate. 30 kg ha-1 DAP was applied across all research plots. Vetch was under sown under the potato crop two weeks after planting potato to minimize investments of land and labour and increase biomass production.

The survey have indicated that decline in land productivity of the outfields is a consequence of multiple natural and human factors (data not presented), firstly due to a continual removal of crop residues from the out field to the homestead field as a mulch, to the stall as feed and to the house as a means of cooking fuel. Secondly, it receives the lowest amount of manure and household refusal because of distance effects and the deliberate favouritism to the homestead infield where the most important security crops, high value crops and planting materials are grown and propagated. Thirdly it is exposed to soil erosion because of limited physical and biological conservation measure in the far away fields. As presented in Table 17 there is a trend of less crop rotation across crops and hence similar crops with the same rooting character were grown year after year. There was almost no manure application to these fields except for farm no. 1, but farmers applied a small amount of chemical fertilizers for major cereal crops like teff and maize. In this system, crops like sweat potato are heavy nutrient miners not only because of their low contribution to the soil but also because of the continual removal of the residue as a planting material, which is as valuable as the tuber.

Earlier work indicated that soil fertility decline in the outfields of this system is not only related to nutrient deficits but also to low soil water holding capacity amid very low organic matter content compared to the infields, which is less the 25% compared to the organic carbon in the homestead fields. There was a significant difference between the after effects of the nitrogen fixing legume, *Vicia dasycarpa* or the incorporation of the crop residue of the preferred crop, potato on wheat yield.

The vetch crop, under sown with potato produced about 5.7 Mg of green biomass in three month time while the biomass of potato was about 4.73 tonnes per hectare. When wheat was following the vetch crop, wheat yield was 60% higher than the control while wheat yield under potato biomass was 42% higher than the control (Table 18). There was no statistical difference between vetch and potato biomass effects while the difference with the control, in both cases, was significant. This result was also confirmed by plant height measurements (Table 18), whereby both treatments were better than the control. However, farmer's ranking indicated that they prefer wheat after potato than the other treatments because of the possibly negative effect of vetch on the companion crop while growing in combination. Laboratory analysis for nutrients and water and also further field experimentation is planned for 2006.

Table 17. Land management history (crop sequence and fertilizer input) of degraded outfield of selected farms in the period of 2001 and 2005 of the research plot (100 m^2) in Areka.

	Farm types															
Year	**1**	**Inputs/ 100 m^2 plot**	**2**	**Inputs / 100 m^2 plot**	**3**	**Inputs / 100 m^2 plot**	**4**	**Inputs / 100 m^2 plot**	**5**	**Inputs / 100 m^2 plot**	**6**	**Inputs / 100 m^2 plot**	**7**	**Inputs / 100 m^2 plot**	**9**	**Inputs / 100 m^2 plot**
2001	Yam	Manure 50 kg	Maize and sweet potato	1 kg DAP	Wheat and sweet potato	4 kg DAP	Barley and Sweet potato				Teff and beans		Teff and beans	4kg DAP for Teff	Maize and sweet potato	1.5 kg DAP
2002	Maize and sweet potato		Maize and sweet potato		Maize	3kg DAP	Maize and pea	6 kg DAP for maize	Maize and potato	3 kg DAP	Wheat and sweet potato	6 kg DAP for wheat	Teff and beans	7 kg DAP	Beans and teff	3kg DAP
2003	Maize and taro	Manure 50 kg	Wheat	2 kg DAP	Wheat and sweet potato	3 kg DAP	Taro	60 kg manure	Fallow and barley		Teff and Sweet potato	6 kg DAP for teff	Teff and beans	7 kg DAP	Maize and sweet potato	2kg DAP
2004	Sweet potato and beans		Maize and sweet potato	1 kg DAP	Beans and wheat	6 kg DAP	Maize and pea	-	Sorghum		Teff and Sweet potato	6 kg for Teff	Teff and beans	7 kg DAP	Maize and sweet potato	2kg DAP
2005	Maize		Fallow				Beans	-	Fallow				Wheat	4kg DAP	Teff	1kg DAP

Table 18. The effect of Vetch or Potato residue biomass on the succeeding wheat crop in the degraded outfield of Gununo. n=8

Treatments	Biomass Yield (Mg ha^{-1})		Grain yield (Mg ha^{-1})		Farmers ranking; One being the best	Plant height	
	Mean	SE	Mean	SE	(1-5)	Mean	SE
Vetch green biomass	5.69	0.88	-	-	-	-	-
Potato residue biomass	4.73	1.18	-	-	-	-	-
Wheat under vetch	2.84	0.35	3.16	0.27	4.44	79.73	1.29
Wheat under potato	2.51	0.29	2.90	0.24	1.11	80.02	1.12
Wheat Control	1.77	0.21	2.15	0.23	3.89	72.20	1.69

Evaluation of best-bet options to combat Striga, stemborers and declining soil fertility in the Lake zone in East Africa

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Following PRA exercises in Kenya, farmers ranked Striga, stem borer and low soil fertility as the major constraints to maize production. Based on this, best-bet strategies for the suppression of Striga and stemborers and improvement of the soil fertility status were identified to be tested in farmer-participatory trials in Kenya, Uganda, and Tanzania.

Components of the best-bet strategies were improved cropping systems ('push-pull', rotations with grain (soybean) and herbaceous (*Crotolaria*) legumes), improved germplasm (herbicide-resistant maize), and fertilizer application. The 'push-pull' strategy uses trap- and repellent plants for management of stemborers. The trap plants, such as Napier grass (*Pennisetum purpureum)* are planted in a border around the maize fields, where invading adult moths become attracted to chemical emitted by the grass. These grasses provide the "pull" in the "push-pull" strategy. Plants that emit chemicals that repel the borers from the maize main crop provide the "Push" in the intercropping scheme. The borer repelling includes members of leguminous genus *Desmodium spp. Desmodium* is planted in between the rows of maize. It also helps maintain soil stability and improve soil fertility through its nitrogen-fixing action. *Desmodium* is easy to harvest and is as a highly nutritious animal feed. A ground cover of Desmodium, inter-planted among the maize, significantly reduces *Striga* growth. Certain legumes have been shown to trigger *Striga* germination without allowing them to grow. In the medium to long term, this suicidal germination may results in substantial *Striga* seed bank depletion in legume-maize rotations. Herbicide-resistant maize contains low doses of herbicide (e.g., 30 g imazapyr a.i./ha), as a seed coat. This manner of delivery act before or at the time of *Striga* attachment to the maize root and prevents the phytotoxic effect of *Striga* on the maize plant, which usually occurs even before *Striga* emergence. Additionally, imazapyr that is not absorbed by the maize seedling diffuses into the surrounding soil and kills non-germinated *Striga* seeds. Effects on *Striga*, stemborers, and soil fertility of these best-bet strategies were compared by using two maize varieties (herbicide-resistant maize and a local landrace or improved commercial variety) under two fertilizer levels (no fertilizer and medium fertilizer). Four demonstration sites were established in Vihiga and Siaya districts in the West of Kenya.

In Kenya, *Striga* emergence was significantly lower in the 'push-pull' system compared to other cropping systems in the 2nd, 3rd and 4th seasons (Figure 28). During the 3rd and 4th season, this reduction was also significant where IR-maize was planted.

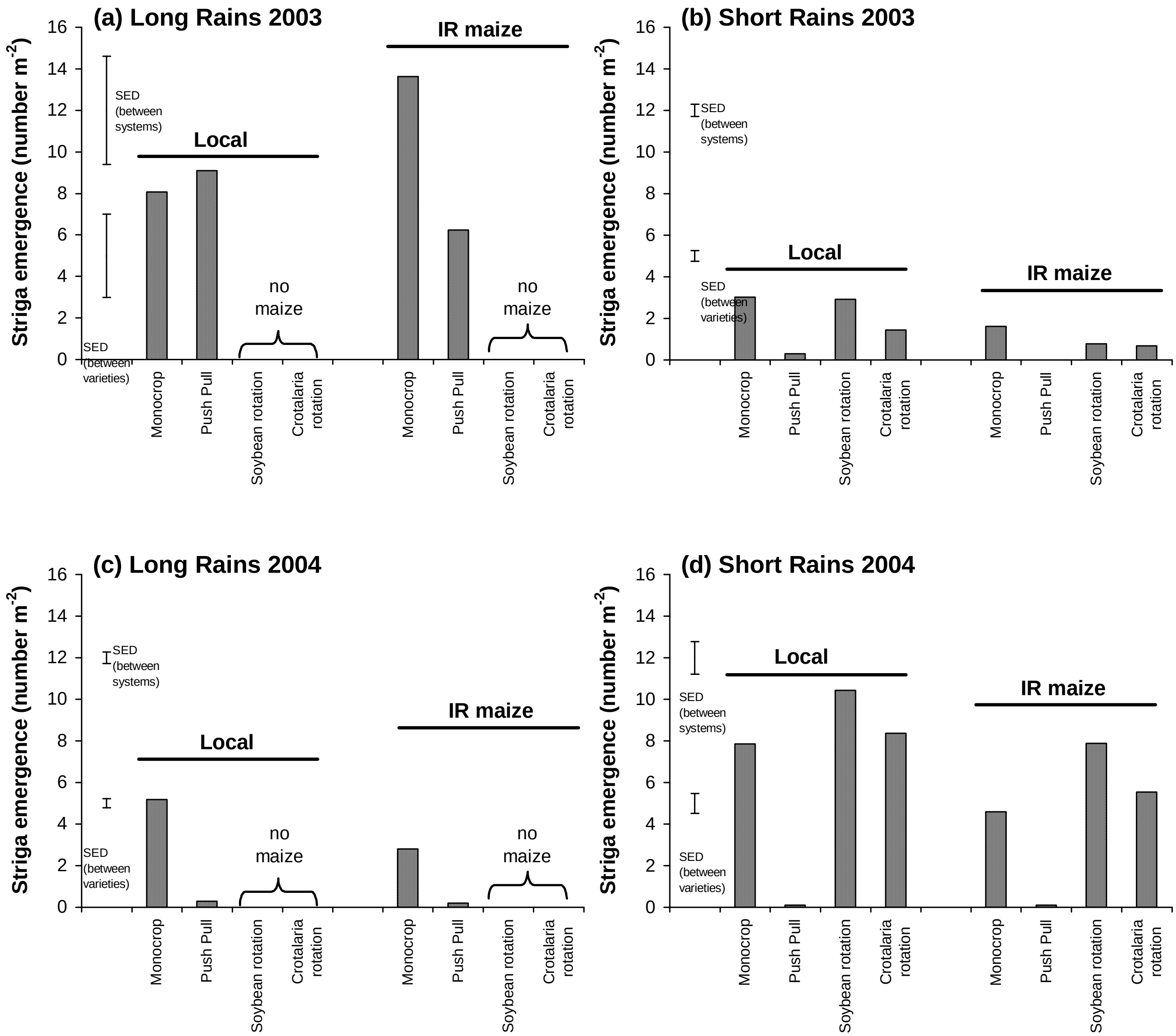

Figure 28. Effect of cropping systems and maize variety on *Striga* emergence in western Kenya. 'IR maize' refers to 'herbicide-resistant maize'.

There was no significant difference in stemborer infestation between districts during the long rains 2003 in Kenya, while in the short rains 2003, there was significant difference between districts with higher infestation in Siaya than Vihiga (Figure 29). Over the seasons, the 'push-pull' cropping system reduced stemborer damage more than any other cropping system in Siaya.

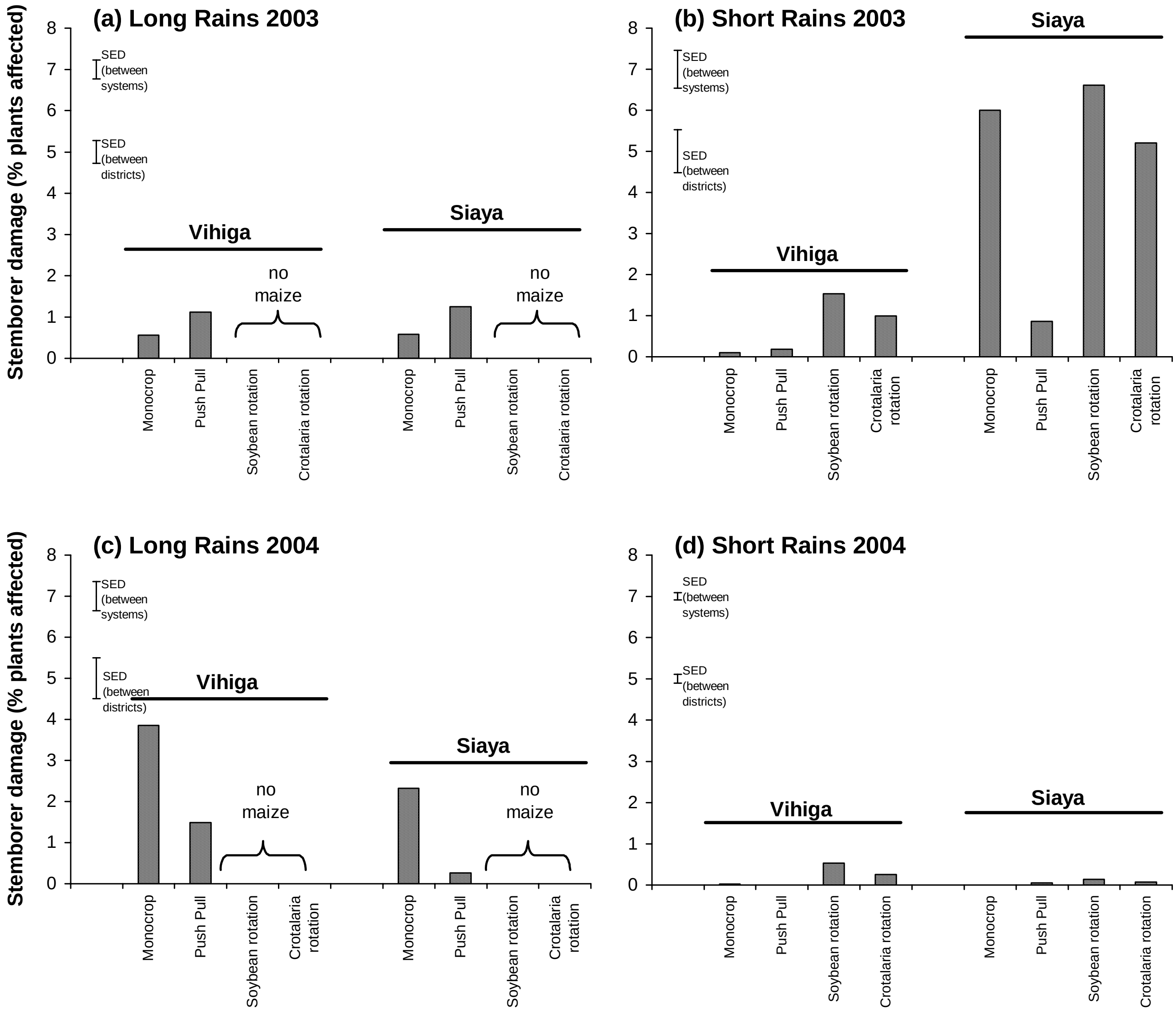

Figure 29. Effect of cropping system and maize variety on stem borer incidence in western Kenya. 'IR maize' refers to 'herbicide-resistant maize'.

Conclusions: The 'push-pull system' was observed to substantially reduce both *Striga* germination and stemborer damage. Herbicide-resistant maize reduced *Striga* germination only during specific seasons. Direct assessments of the Striga seedbank will reveal whether the rotations have effectively reduced the number of viable seeds in time.

Output target 2007

- ***Banana, bean and cassava-based systems, with the relation between pest, diseases and ISFM as entry point, including novel cropping sequences, tested and adapted to farmer circumstances in Africa***

Work in progress

Evaluation of the potential of arbuscular mycorrhizal fungi to enhance the initial growth of tissue culture bananas

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The tissue-culture is a promising technique to avail improved and homogeneous banana germplams to farmers. The current activity aims at identifying the best arbuscular mycorrhizal fungi (AMF) strains for inoculation of tissue culture bananas and quantifying the impact of such inoculation on banana survival, growth, and production. Specific objectives are (i) to assess the AMF-dependency of tissue culture bananas using existing AMF cultures, (ii) to determine the AMF diversity in banana plantations, and (iii) to identify the best indigenous strains for inoculating tissue culture bananas.

Arbuscular mycorrhizal fungi have the potential to improve the performance of tissue culture bananas in poor soils. The magnitude of response may vary between species and within species. Therefore, prior to establishment of tissue culture cultivars in poor soils, the response of different cultivars to different AMF isolates was determined. A greenhouse experiment was set up to determine the dependency of different tissue culture cultivars on different AMF isolates. Five desert bananas (Giant Cavendish, Williams Hybrid, Grand Nain, Gros Michel, and Dwarf Cavendish) were supplied by JKUAT, Nairobi, and plantlets of four cooking (Kisansa and Mbwazirume) and two desert (Mpologoma and Nakitembe) were supplied by Agrogenetics, Kampala. Four AMF inocula (*Glomus etunicatum*, *Glomus mosseae*, *Glomus intraradices*, and *Gigaspora albida*) were used. Mass production of the inoculum was done on sorghum grown in river sand. After inoculation with AMF, the tissue culture plantlets were grown in pots on river sand and nourished with modified Hewitt nutrient solution.

Banana growth was observed to be substantially enhanced after inoculation with *Glomus Etunicatum* and *Glomus intraradices*, followed by *Glomus mosseae* (Figure 30). *Gigaspora albida* did not influence banana growth.

Conclusions: Inoculation with AMF shows considerable potential to enhance the early growth of tissue-culture bananas, although observations after transplanting the plants under field conditions and observing their growth and production under field conditions is required before firm conclusions can be drawn. Fungi isolated from existing banana plantations could further outperform the strains used in the current trial, which is one of the follow-up activities currently being implemented.

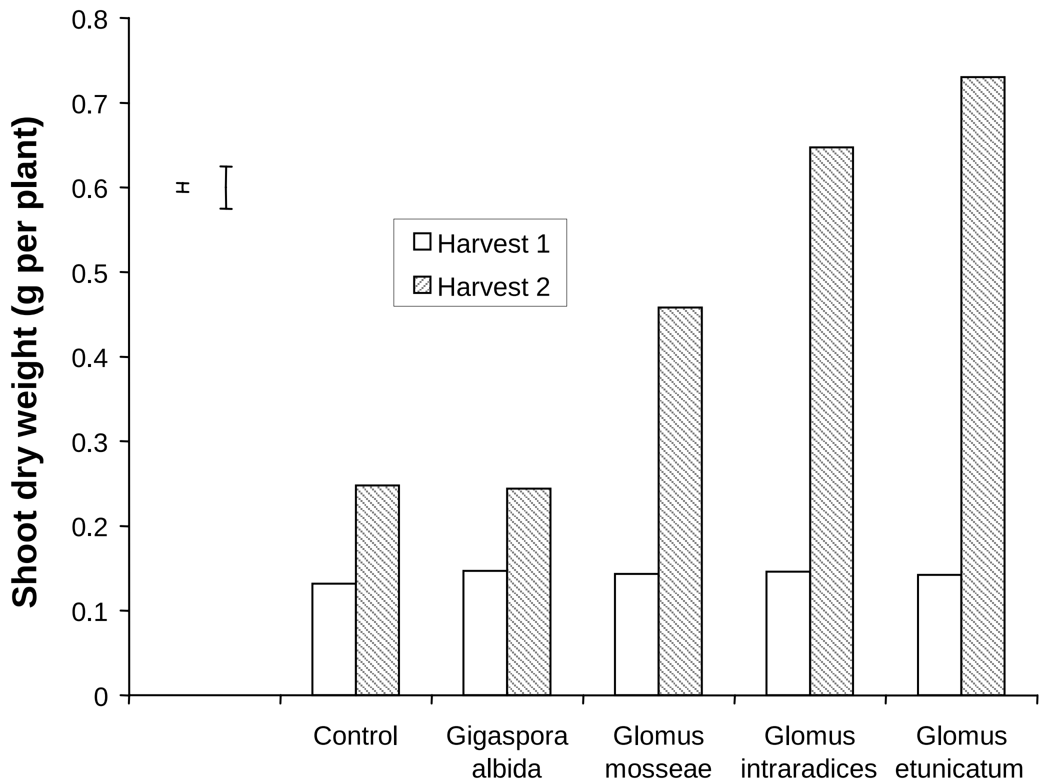

Figure 30. Shoot dry weight of different banana cultivars as affected by inoculation with different strains of AMF.

Determination of the most limiting nutrients for East African highland banana production, as affected by pest and diseases.

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

Trials, using a randomized complete block design with a set of mineral inputs x pesticide application treatments (Table 19), have been established in Maragua district in Kenya and in Ntungamo and Mpigi districts in Uganda. In Kenya, Cavendish, a popular desert cultivar, and in Uganda, Kisansa, a popular cooking cultivar is used as test crops.

Table 19. Treatment structure of the on-station nutrient omission trials.

Treatment	1	2	3	4	5	6	7	8	9	10
N	X	-	-	½	X	X	X	X	-	X
P	X	-	X	X	-	X	X	X	-	X
K	X	-	X	X	X	-	½	X	-	X
S + Micro-nutrients	X	-	X	X	X	X	X	-	-	X
Pesticide	X	X	X	X	X	X	X	X	-	-

After 4 months of growth (most of this period, bananas were irrigated), plant height and girth diameter were lowest for the no-input control treatments, both in absence or presence of pesticides (Figure 31). Significant responses to missing N, P, and S + micro-nutrients were observed for plant height and girth diameter. Pesticide application did not have a significant impact on plant growth at his early stage of banana growth. Interesting to note are the clear differences in leaf color as affected by not applying S and micro-nutrients, pointing at limitations of at least one of those nutrients.

Conclusions: Initial observations show significant enhancements in banana growth after application of specific combinations of nutrients. Crop yield data will be needed to measure the impact of specific nutrient stresses on final production. The representativeness of the site used for the trial will be assessed through comparing soil information from the current site with soil information from the banana plantation characterization work, carried out at an earlier stage of the project.

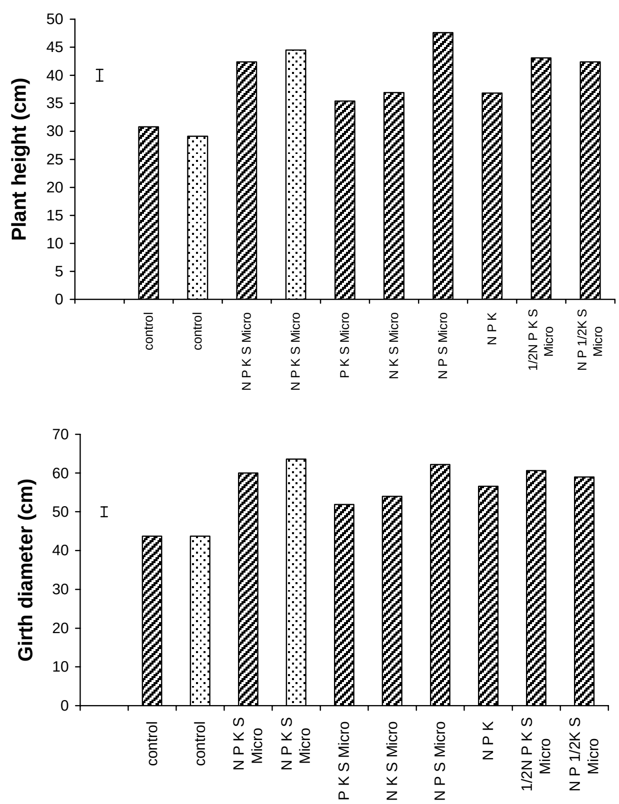

Figure 31. Plant height and girth diameter of 4-month old bananas at the Maragua on-station nutrient omission trial. Micro-nutrients used are Zn, Mg, B, and Mo. '1/2' refers to half the application of that

specific nutrient. Bars with dots are treatments which do not receive pesticides to control weevils and nematodes, all other treatments receive pesticides.

Output target 2007

➢ ***Cereal-legumes and livestock systems, with nutrient use efficiency as an entry point, tested and adapted to farmer circumstances in acid soil savannas***

Work in progress

Residual effect of building an arable layer on maize yields

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TSBF-CIAT

The main objective of this work is to determine the residual effect of the construction of an arable layer on maize yields in the Easter Plains of Colombia. During a period of three years (2001 to 2004), a field experiment was conducted to investigate different strategies for the construction of an arable layer in a soil (Typic Haplustox Isohypertermic Caolinitic) of the flat Altillanura. For this purpose a randomized block experimental design with 13 treatments and three replicates was used. Native savanna (treatment 13) was used as control treatment. Experimental plots were of 40×41m. Treatments involved three factors: 1) three different sequences of crop rotations (Table 20), 2) two sources of calcium and magnesium (dolomitic lime and sulcamag), and 3) two depths of tillage with rigid chisels (0-15; 0-30 cm).

Table 20. Sequences of crops established for the construction of arable layer from 2001 to 2003.

Crop sequences No	Year 2001		Year 2002		Year 2003
	Semester A	Semester B	Semester A	Semester B	Indicators crops
1	Rice Line 30	Rice Line 30	Maize H-108	Millet + Legumes (*)	Maize H-108 vs (MHY) (***)
2	Rice Line 30 + *B. brizantha*	*B. brizantha* (**)	Maize H-108	Soybean P-34	Maize H-108 vs (MHY) (***)
3	Rice Line 30 + *B. brizantha* + *D. ovalifolium*	*B. brizantha* + *D. ovalifolium*	Maize H-108	Millet + Legumes (*)	Maize H-108 vs (MHY) (***)

*   Forage legumes = *Pueraria phaseoloides* + *Desmodium ovalifolium*
** Forage grass = *Brachiaria brizantha*
*** (MHY) = Maize with high yield potential

Table 21 shows the treatments. Depth of tillage was initially (0-15cm) in the first year and became deeper (0-30 and 0-45cm) in the second year. This decision was taken, because soils are very hard and it is not advisable to force the soil to be broken down by chisels or to damage the chisels. So a gradual improvement of soil with depth was planned.

The criterion for the application of the lime was to apply a quantity that is enough to achieve a calcium + magnesium saturation of 70% in two years at the respective soil depths of improvement. The quantity of lime to be applied was split into two applications, 50% at the beginning of the first year and 50% at the beginning of the second year.

Table 21. Details on the distribution of soil amendments by crop sequences and depth of tillage.

Treatment No	Crop Treatment No	Crop sequences No	Depth of tillage (cm)	
			Year 2001	Year 2002
1	1	100% lime	0 to 15	0 to 30
2	1	75% lime + 25% Sulcamag	0 to 15	0 to 30
3	1	100% lime	0 to 30	0 to 45
4	1	75% lime + 25% Sulcamag	0 to 30	0 to 45
5	2	100% lime	0 to 15	0 to 30
6	2	75% lime + 25% Sulcamag	0 to 15	0 to 30
7	2	100% lime	0 to 30	0 to 45
8	2	75% lime + 25% Sulcamag	0 to 30	0 to 45
9	3	100% lime	0 to 15	0 to 30
10	3	75% lime + 25% Sulcamag	0 to 15	0 to 30
11	3	100% lime	0 to 30	0 to 45
12	3	75% lime + 25% Sulcamag	0 to 30	0 to 45
13	Savanna	Control	No amendment	No amendment

* Lime = 56% de $CaCO_3$ and 34% of $MgCO_3$ (Sieved in 100 MESH)

Sulcamag = 61% of $CaSO_4$ and 39% of $MgSO_4$

Sequence 1 emphasized soil physical improvement with more lignified crops (Rice and millet). Sequence 3 emphasized on organic and biological improvement working with materials of better quality (grass and Legumes). The sequence 2 was an intermediate strategy (Table 20). Lime and sulcamag as soil amendments were incorporated with chisel only for the crop of the first semester every year. Second semester crops were sown with a direct drilling machine. Fertilization was done in accordance with the recommendations for the region. When necessary, control of insects, diseases and weeds was done.

After three year of evaluations, it was concluded that in all treatments implemented to build up an arable layer, physical and chemical soil constraints were overcome in relation to native savanna and that maize yields, did not show significant differences between the treatments. Average yields of maize varied between 6,475 and 7,406 kg ha^{-1} in the 0-30cm soil depth and between 6,121 and 7,448 kg ha^{-1} when the depth of chisel was 0-45cm depth. The combination of lime + sulcamag was better than the application of lime alone.

During year 2004 no land preparation was made in the experimental area, but kudzu was sown and left to protect the soil. Dry matter of this species reached values that varied between 11 to 13 Mg ha^{-1}. At the beginning of the rainy season of 2005 *Pueraria phaseoloides* was eliminated and maize was sown under the system of direct drilling. Fertilization was calculated on the basis of the amount of nutrients needed to produce seven tons of maize grain yield per hectare. The quantities used were: 150, 64, 140, 0.4 and 2 kg/ha of N, P_2O_5, K_2O, B and Zn respectively. Atrazine was applied after sowing for control of weeds. Maize seed of (Pioneer hybrid 3041) was sown placing six seeds per a length of one meter in a row.

Table 22 shows the yields obtained in maize. There were no significant differences between treatments, showing that there was a good residual effect of the building up of the arable layer and that it is possible to produce high yields using the concept. The yields obtained were the double or triple of the yields obtained under traditional systems (1500-2500 kg ha^{-1}). If maize is sown in savanna soils without any land preparation, soil amendment (lime) or fertilizers, it is not possible to produce maize in these soils.

Table 22. Grain yields of maize in 2005 with different treatments used to construct arable layer.

Crops sequences	**Maize yields (kg/ha)**			
	Depth 0-30 cm		**Depth 0-45 cm**	
	Lime	**Lime+Sulcamag**	**Lime**	**Lime+Sulcamag**
Crop rotations	6475	6515	6121	7349
Crops + grass	6765	6921	6539	7448
Crops + grass + legumes	6631	7406	6816	7368

Output target 2008

- ***Communities in at least three countries demonstrate and test direct or indirect management options that enhance locally important ecosystem services using BGBD***

Published work

R. Duponnois[1] and D. Lesueur[2] (2005) Sporocarps of Pisolithus albus as an ecological niche for fluorescent pseudomonads involved in Acacia mangium Wild – Pisolithus albus ectomycorrhizal symbiosis. Canadian Journal of Microbiology 50: 691-696
[1]IRD/Burkina Faso; [2]TSBF-CIAT
Fresh sporocarps and root and soil samples were collected under a monospecific forest plantation of *Acacia mangium* in Dagana in Northern Senegal and checked for the presence of fluorescent pseudomonads. No bacteria were detected except from sporocarps collected with adhering soil and hyphal strands. *Pisolithus* sporocarps were dried at 30 °C for 2 weeks, ground, passed through a 2-mm sieve and mixed together. This dry sporocarp powder (DSP) was used to inoculate and form mycorrhizas on *A. mangium* seedlings in a glasshouse experiment. After 3 months culture, plant growth was increased in the DSP treatment but no ectomycorrhizas were present on the *A. mangium* root systems; however fluorescent pseudomonads were recorded in the cultural soil. The stimulatory effects on the plant growth were maintained for 6 months. However, fluorescent pseudomonads were no longer detected and 35% of the short roots were ectomycorrhizal. Some of the fluorescent pseudomonad isolates detected after 3 months stimulated the radial fungal growth in axenic conditions. These observations suggest that these bacteria are closely associated with the *Pisolithus* fructifications and could interact with the ectomycorrhizal symbiosis establishment.

Work in progress

BGBD project
The demonstration of direct and indirect management options for the conservation of BGBD and enhancement of ecosystem services is subject of the second phase of the project. In 2005 the various countries have made a first attempt to identify relevant management option for consideration during the second phase. These may include use of *Trichoderma* and *Bacillus thuringiensis* as agents of biological control of pest and diseases, and push-pull approached in combination with crop rotation also in view of control of pest an diseases to name two options considered by the Kenyan BGBD team as examples. In general the ecosystem services targeted will concern soil structure modification and improved soil water balance, pest and disease control, nutrient cycling and soil fertility enhancement and carbon sequestration and reduction of greenhouse gas emissions.

Output target 2008

- ***Quesungual and other related agroforestry systems, with soil and water conservation as entry point, including crop diversification strategies, tested and adapted to farmer circumstances in Central America***

Work in progress

Quesungual slash and mulch agroforestry system (QSMAS): Improving crop water productivity, food security and resource quality in the sub-humid tropics

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The Quesungual Slash and Mulch Agroforestry System (QSMAS) has contributed to a successful development strategy in improving rural livelihoods in the Lempira Department, Honduras. This alternative to slash and burn agriculture strongly builds on local knowledge and has been a major production system to achieve food security by resource poor farmers. The widespread adoption of the QSMAS by more than 6,000 farmer households has been driven by a two-fold increase in crop yields and cattle stocking rates and significant reduction in costs associated with agrochemicals and labor. Farmers recognize that a remarkable feature of the QSMAS is the increased soil water holding capacity and extended time of soil water availability thus preventing crop failures. Besides making a substantial contribution to food security, QSMAS has shown a remarkable degree of resilience to extreme water deficits and also to excess water during natural catastrophes.

In 2004 the Water and Food C.P approved financial support to determine the key principles behind the social acceptance and biophysical resilience of QSMAS. The specific objectives of the project are: 1) To assess socioeconomic and biophysical context of QSMAS; 2) To define QSMAS management concepts and principles and to develop relevant tools to monitor soil and water quality; 3) To evaluate and document potential areas suitable to QSMAS and 4) To develop tools for dissemination, adaptation and promotion of the QSMAS management strategies.

The target area is characterized by steep slopes >40%, shallow soils (Entisols) with low pH (<5.1) and generally with low amounts of available phosphorus. Annual precipitation is about 1400 mm (target region of <900 m.a.s.l.) and the rainy season lasts from early May to the end of October with a long dry season of up to six months. The extent of water deficit in the middle of the dry season is over 200 mm. The average annual temperature varies from 17 to 25°C. During the dry season from early November to April, strong winds blow from the North and the enhanced evapotranspiration rates cause a severe water deficit until the onset of rains.

Field research is being conducted with strong participation of the MIS consortium in Central America, a network of biophysical and socioeconomic researchers and extension agents from NARES and universities from Honduras and Nicaragua.

Expected outputs of this work will be***:*** 1) **Principles** regulating soil-water cycle and C storage in QSMAS understood and applied to other similar regions in pilot watershed areas of Honduras and neighboring countries; 2) **tools**, methodology and data sets relevant to quantify water quality and availability at plot, farm and landscape levels; 3) **Scenarios** of impact of intensification and diversification processes on water quantity and quality of the adopted QSMAS for the upstream and downstream users; 4) Increased farmer's **income** by 20% to 30% through QSMAS-driven enhanced water availability and use efficiency;

5) **Cleaner water** (water with few sediments) produced for downstream users (human and animal consumption), as an added QSMAS environmental service and 6) **Trained personnel** from National Programs and NGOs in the use of field methodologies to assess water quality and soil water storage capacity.

Preliminary results

Table 23 shows the main outcomes of the work during the first year of the project. In general, QSMAS is inserted in the landscape within a mosaic of natural tree vegetation at different stages of regrowth because of the elimination of burning in the region. Soil losses are negegible and water conservation is increased because of permanent mulch on the soil. Preliminary results are showing that soil losses under QSMAS of different ages (2, 5 and >10 years), were less than 2 Mg ha^{-1} in 14 weeks in comparison to the 30 Mg ha^{-1} losses observed in the slash and burn treatments. Excess water leaving the system by runoff is almost clean and can be used by downstream users. However, there are methodological challenges to determine water dynamics in the soil because of the high proportion of stones in the soil. Crop yield data is indicating that there is a strong interaction between soil fertility, water availability and crop productivity.

Table 23: Main outcomes of the project during the first year of the QSMAS project.

Project output/s	Main outcomes
1. Socioeconomic and biophysical context of QSMAS assessed and information assembled into a data base.	• A Digital elevation model of the area of influence of the QSMAS developed containing information on slope, land use, climate and altitude. • Collection and analysis of available socioeconomic information. • Main farm typologies identified with emphasis on water driven processes.
2. QSMAS management concepts and principles defined and relevant tools developed to monitor soil and water quality.	• Definition of research protocols and methodologies. • Selection of farms to study the plant, soil, water and gas components of QSMAS. • Establishment of the field experiments to asses the effect of soil fertility and QSMAS age on crop productivity. • A better understanding of the system at plot, farm and landscape level. • Allometric equations developed to estimate biomass and carbon accumulation of dominant trees in the system.
3. Potential areas suitable to QSMAS evaluated, analyzed and documented.	• Participatory selection of the Somotillo region in Nicaragua to validate the QSMAS • Establishment of six on-farm validation plots to compare QSMAS against traditional management systems.
4. Tools for dissemination, adaptation and promotion of the QSMAS management strategies developed.	• Farmer to farmer exchanges, field tours and periodic press releases. • 3 MIS Bulletins prepared highlighting progress on project implementation. • Identification of 2 PhD, 2 MSc and 6 BSc candidates from the region

Progress towards achieving output level outcome

- *Technologies, systems and soil management strategies adopted and adapted through partnerships*

In Output 2, the main objective is to develop and adapt technologies and soil management strategies that are encompass the various principles and concepts developed in Output 1, through partnerships with all stakeholders. This development and adaptation process includes various phases with increasing direct involvement of farming communities and other stakeholders. During the initial phases, knowledge, often derived from detailed literature reviews, is translated in soil management practices with relatively little involvement of stakeholders. As technologies move away from the design phase to the farmer's fields, farmers and other stakeholders gradually take over the evaluation and adaptation process.

Most reports under Output 2 deal with the development of testing of a decision framework for ISFM and with the testing and adaption of cereal-legume-livestock systems in Africa. As for the former set of activities, results are reported that relate to the site-specific management of resources (e.g., legume biomass, P, manure) at the farm-level, taking into account variability at the natural resource status and community level. As for the latter set of activities, a substantial number of abstracts summarize detailed reviews of the role of manure in soil fertility maintenance and of soil fertility management strategies for West, East, Central, and southern Africa. Other specific activities relate to the identification and utilization of specific production niches at the farm level, such as, niches for green manure production in Ethiopia, or vegetable gardens in Kenya. Cotton-cowpea systems in Zimbabwe, legume-based striga control technologies in Kenya, Uganda, and Tanzania, and soybean varieties in Kenya are being evaluated using participatory approaches. Finally, certain abstracts have investigated the success and failures of specific soil fertility management options, evaluated through community-based learning process and collective and individual experimentation.

The development and evaluation of technologies aiming at improving the productivity of banana and cassava-based systems in Africa and cereal-legume-livestock systems in Latin America have just reached the initial design phase with promising initial results related to nutrient management of bananas and inoculation of tissue culture bananas with arbuscular-mycorhizal fungi. The evaluation of direct and indirect management options of belowground biodiversity and the Quesungual agroforestry systems has also just been initiated with some preliminary ex-ante evaluation of the latter.

Progress towards achieving output level impact

- *Adapted technologies contribute to food security, income generation and health of farmers*

In Output 2, only the cereal-legume-livestock systems have reached a stage that impact of adoption of such technologies will contribute positively to food security, income generation and health of farmers. This initial adoption phase will be followed in future activities. As for the other technologies and entry points, an evaluation and adaptation phase is required before any impact can be expected.