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.

Key research questions:

1. What are the key components (labor, fertilizers, germplasm, BGBD, etc.) to manage in a given context for increased profitability, system productivity, and resilience?
2. How can we optimize the benefits between production and resource conservation?

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***

Work in progress

The CSM-BGBD project established experimental and demonstration trials during 2007. Though in most cases these refer to controlled experiments they are conducted within the benchmark sites and some on farmers' fields. In all case there is active participation of the farmer community be it by being directly involved in the implementation of the trials, by the organization of farmer's fields days and through participatory monitoring and evaluation exercises. The project expects that these activities will lead to adoption of the techniques by farmers.

Output target 2009

➢ ***Local baselines and interviews show that farmers' understanding of soil processes is demonstrably enhanced within community-based experimentation in at least 5 benchmark sites***

Published work

Mairura[1], F.S., Mugendi[2], D.N., Mwanje[2], J.I., Ramisch[1], J.J., Mbugua[3], P.K. and Chianu[1] J. N. (2007) Scientific evaluation of smallholder land use knowledge in central Kenya. Land Degradation & Development 18: 1–14.
[1]CIAT-TSBF, Kenya; [2]Department of Environmental Resource Conservation, Kenyatta University, Kenya; [3]Department of Botany, Kenyatta University, Kenya
Abstract: The following study was conducted to determine smallers' land use management practices and agricultural indicators of soil quality within farmers' fields in Chuka and Gachoka divisions in Kenya's Central Highlands. Data on cropping practices and soil indicators were collected from farmers through face-to-face interviews and field examinations. Farmers characterized their fields into high and low fertility plots, after which soils were geo-referenced and sampled at surface depth (0–20 cm) for subsequent physical and chemical analyses. Farmers' indicators for distinguishing productive and non-productive fields included crop yields, crop performance and weed species. Soils that were characterized as fertile had significantly higher chemical characteristics than the fields that were of poor quality. Fertile soils had significantly higher pH, total organic carbon, exchangeable cations and available nitrogen. Factor analysis identified four main factors that explained 76 percent

of the total variance in soil quality. The factors were connected with farmers' soil assessment indicators and main soil processes that influenced soil quality in Central Kenya. Soil fertility and crop management practices that were investigated indicated that farmers understood and consequently utilized spatial heterogeneity and temporal variability in soil quality status within their farms to maintain and enhance agricultural productivity.

Mairura[1], F.S., Mugendi[2], D.N., Mwanje[2], J.I., Ramisch[1], J.J., Mbugua[3], P.K. and Chianu[1] J. N. (2007) Integrating scientific and farmers' evaluation of soil quality indicators in Central Kenya. Geoderma 139: 134 – 143
[1]CIAT-TSBF, Kenya; [2]Department of Environmental Resource Conservation, Kenyatta University, Kenya; [3]Department of Botany, Kenyatta University, Kenya
Abstract: A study was conducted to determine farmers' perceptions of soil quality and common soil management practices that influenced soil fertility within farmers' fields in Chuka and Gachoka divisions, Kenya. Soils were characterized by smallholders after which they were geo-referenced and sampled at surface depth (0–20 cm) for subsequent physical and chemical analyses, to determine differences within farmers' soil quality categories. Indicators for distinguishing productive and non-productive fields included crop yield and performance, soil colour and soil texture. There were significant differences among soil fertility categories, using parametric techniques (ANOVA) for key soil properties ($p<0.005$), implying that there was a qualitative difference in the soils that were characterized as different by farmers. Fertile soils had significantly higher pH, total organic carbon, exchangeable cations and available-N. Factor analysis on 15 soil properties identified 4 main factors that explained 68% of the total variance in soil quality. The four Varimax-rotated factors were designated as contrasts that described soil quality status on farmers' fields. The first factor grouped calcium, magnesium and soil pH, while the second component comprised available nitrogen, organic carbon and total nitrogen. The third factor included plant nutrients mainly extractable phosphorus and available nitrogen, while the fourth factor comprised soil physical properties (macroaggregates, microaggregates, silt, and clay). Soil fertility and crop management practices that were investigated indicated that farmers understood and consequently utilized spatial heterogeneity and temporal variability in soil quality status within their farms as a resource to maintain or enhance agricultural productivity.

Work in progress

Natural Resource Management Options demonstrated and evaluated in the mandate areas of the CIALCA / TSBF-CIAT project.

P. Pypers[1], S. Kantengwa[2], J.P. Lodi-Lama[3], K. Musale[4], S. Mapatano[5], L. Nabahungu[6], T. Ngoga[6], C. Ndayisaba[6], F. Habitigeko[6], J. Lunzihirwa[4], W. Bimponda[3], L. Lubanga[7], T. Hangy[7], J.M. Sanginga[8], K. Bishikwabo[8], M. Manzekele[3], A. Chifizi[5], P. Sanginga[9], and B. Vanlauwe[1]

[1]CIAT-TSBF, Kenya; [2]CIALCA, Rwanda; [3]CIAT/INERA, Kinshasa; [4]CIALCA, Bukavu; [5]Diobass, Bukavu; [6]ISAR,Rwanda; [7]INERA, Bukavu; [8]CIAT,Bukavu; [9]IDRC, Kenya

Overview of options currently being tested

Testing of natural resource management (NRM) options started in March 2007 (season 2007 B) or in September 2007 (season 2008 A). These options were chosen to address some of the major constraints identified, and were targeted towards the specific conditions in the regions and action sites. Partners as well as farmer groups were involved in the process of selecting and developing options. In most sites, proven NRM options that were successful elsewhere (improved agronomic practices and nutrient management in legume-cereal rotation or intercropping, and cassava-legume intercropping systems) were immediately implemented as demonstration trials with farmer associations. Other technologies, requiring additional research and adjustment to the local conditions, were implemented on-station before engaging with farmer associations. These include technologies for soil erosion control, tested in Sud-Kivu (DRC), and rain water harvesting in combination with efficient nutrient management to counteract seasonal drought spells in Umutara (Rwanda). At present, a total number of 56 farmer associations are actively involved in the testing, management and evaluation of demonstration trials in the various action sites across the 4 mandate areas

(Table 14). In addition, 50 households in the Nyakigando action site (Umutara, Rwanda) started implementing adaptation trials in September 2007 (season 2008 A) after having appraised the technologies demonstrated earlier in legume-cereal intercropping systems.

An improved bean-maize intercropping system, demonstrated in Kabarore, Umutara, Rwanda.

Presented below are selected results for NRM options on erosion control and improved cassava-legume intercropping.

Table 14: An overview of NRM research, demonstration and adaptation trials conducted in 2007 in the various action sites of the TSBF-CIAT project.

NRM option	acronym	trial type	location	period	involvement of farmer associations
Erosion control using legume hedgerows and reduced tillage as alternatives to terrace construction	"ERO-1"	on-station (research)	on-station at Mudaka (Sud-Kivu)	installed in March 2007 (currently running the 3rd season)	on-station activity but the local farmer community is involved in the management of the trial.
Rainwater harvesting and interaction with nutrient management to counteract seasonal drought spells	"WANU-1"	on-station (research)	on-station at ISAR-Karama and ISAR-Nyagatare (Rwanda)	installed in March 2007 (currently running the 3rd season running)	on-station activity – the activity aims to identify promising options before engaging with farmer associations
Improved agronomy options in cassava-legume intercropping systems	"CAS-1"	demonstration trials	2 locations, in Zenga and Nkamu in Bas-Congo	installed in April 2007 (on-going)	2 farmer associations are involved in the management and evaluation of the demonstrated options.
Improved agronomy options in cassava-legume intercropping systems	"CAS-2"	demonstration trials	6 locations, in Kabamba in Sud-Kivu	installed in September 2007 (on-going)	3 farmer associations are involved in the management and evaluation of the demonstrated options.
Improved soil fertility management in cassava systems	"CAS-3"	demonstration trials	2 locations, in Kisantu and Mbanza-Nzundu in Bas-Congo	installed in April 2007 (on-going)	2 farmer associations are involved in the management and evaluation of the demonstrated options.
Erosion control using leguminous and non-leguminous forage hedgerows as an alternative to terrace construction	"ERO-2"	demonstration trials	6 locations, in action sites in Sud-Kivu	installed in March 2007 (on-going)	6 farmer associations are involved in the evaluation of the forage species. The trial has been combined with multiplication of improved cassava germplasm.

Soil fertility amendment using various organic and inorganic inputs on poor soils	“FER-1”	demonstration trials	8 locations, in Mwegerera and Lurhala in Sud-Kivu	installed in March 2007 for one season (concluded)	6 farmer associations have been involved in the testing of soil fertility management options.
Improved cereal-legume intercropping options	“SYS-1”	demonstration trials	8 locations, in action sites in Umutara, Rwanda	installed in September 2006 (currently running the 3rd season)	8 farmer associations have been involved in the management and evaluation of the demonstrated options.
Demonstration of rotational benefits of high-biomass- yielding legume varieties and the micro-dose fertilizer technique	“SYS-2”	demonstration trials	6 locations, in Luhihi in Sud-Kivu	installed in September 2007 (on-going)	3 farmer associations are involved in the management and evaluation of the demonstrated options.
Demonstration of rotational benefits of soybean and Mucuna on a subsequent maize crop	“SYS-3”	demonstration trials	30 locations, in Lemfu in Bas-Congo	installed in October 2007 (on-going)	30 farmer associations (through the network of NGO partner BDD) are involved in the management and evaluation of the demonstrated options.
Adaptation of cereal-legume intercropping options	“ADA-1”	adaptation trials	50 locations in Nyakigando, Umutara, Rwanda	installed in September 2007 (on-going)	50 individual households are testing and adapting the previously demonstrated options in their own farms.

Soil conservation technologies tested in Sud-Kivu (“ERO-1” and “ERO-2)

In Sud-Kivu, high population has driven agriculture towards fragile land and soil erosion has become one of the major threats to agricultural production. Legume-grown fields are predominantly located on lands with strong slopes and commonly unprotected against erosion. Inadequate soil conservation measures have given rise to rapid loss of topsoil and land degradation. In Rwanda, effective policies and community work arrangements are in place for large-scale terrace construction and combating soil erosion. These are however absent in Sud-Kivu, where the situation calls for alternative, less labour-intensive technologies that are acceptable and adoptable by individual households.

Severe soil degradation in land with a high slope cropped with beans in Sud-Kivu, DRC.

Two trials were set up in March 2007 to evaluate alternative options for combating soil erosion. A first trial (“ERO-1”) aimed to compare the effectiveness in conserving soil of reduced tillage and planting hedgerows of a leguminous perennial, *Calliandra callothyrsus*, with the construction of physical terraces. This trial was set up on-station in 3 replicates, on a site with a strong slope (41 %), following a complete factorial design with factors (i) terrace construction, (ii) tillage, and (iii) *Calliandra* hedgerows. A second trial (“ERO-2”) was installed in 6 sites in farmers’ environment and aimed to examine the adaptability of various forage species when grown as hedgerows on representative slopes, and to obtain farmers’ feedback on the adoption potential of these forages.

On-station testing of soil conservation measures ("ERO-1")

In this trial, the soil is cropped with soybean in rotation with maize, and the short- and long-term effects of reduced tillage, planting *Calliandra* hedge rows, and installing physical terraces on crop production and soil conservation are assessed. The measurements conducted in this trial include: (i) crop grain yield, (ii) changes in slope and soil loss, (iii) soil water profiles, and (iv) changes in soil fertility. A detailed description is given in the trial protocol. Presented below are selected results from the first and second season, grown with soybean and maize, respectively.

Extension programs recommend a vertical distance of 1.6 m between two contour lines for terrace construction or hedgerow planting. This translates into a plot width of 4 m for the given slope at the trial site. The installation of terraces by embanking the soil up-hill and hedgerow planting entail a loss of surface area available for cropping, equal to 27% and 20%, respectively **(Figure 20)**. This implies that grain yields per unit area need to increase by 37% and 25%, respectively, to compensate for these area losses, and to justify the use of these techniques by farmers.

Soybean cropping without (above) or with (below) physical embankments.

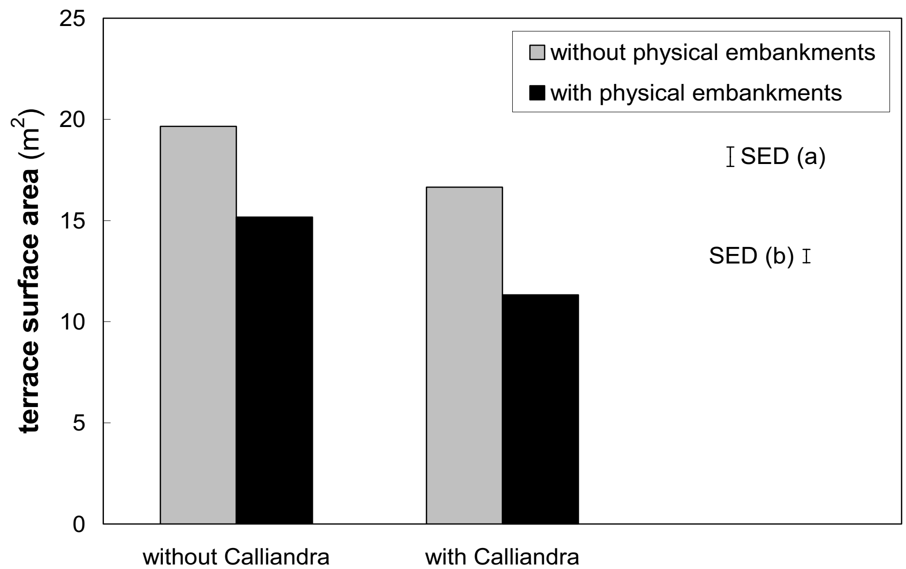

Figure 20: Plot surface area (for a plot length of 5m and a vertical interval of 1.6m) as affected by terrace construction and hedgerow planting; error bars represent SED, comparing (a) with and without terraces, and (b) with and without hedgerows

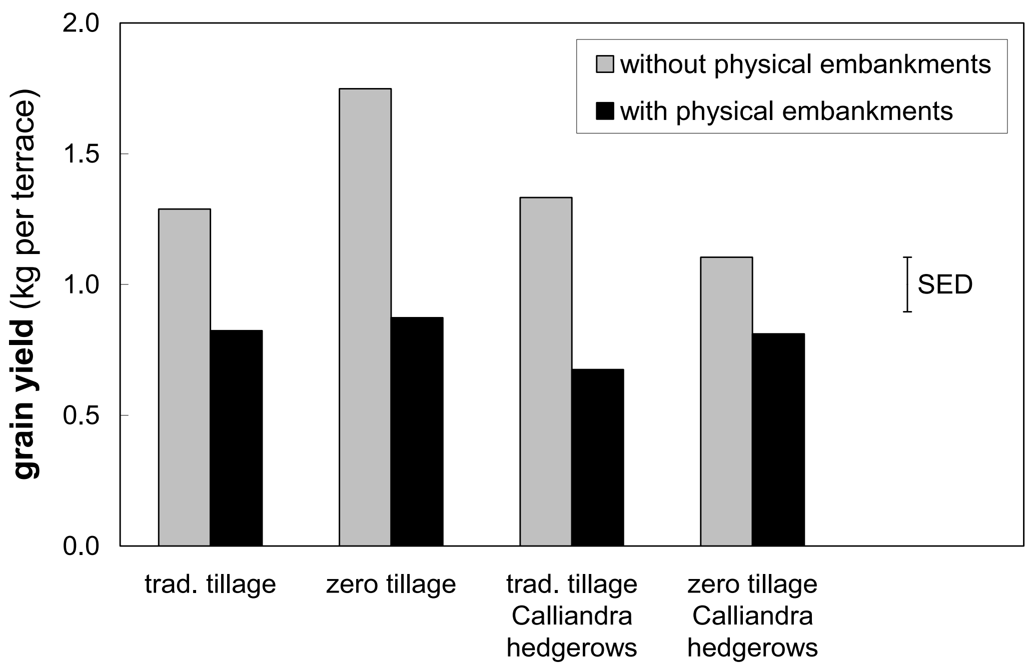

Figure 21: Grain yields obtained per plot (for a plot length of 5m and a vertical interval of 1.6m) as affected by tillage, terrace construction and hedgerow planting; the error bars represents SED.

In the first season, soybean grain yields obtained per plot (dimensions: length = 5m, vertical interval = 1.6 m) were significantly lower in plots with physical terraces **(Figure 21).** This was primarily related to the loss of surface area available for cropping. Plots without physical embankments could generally hold 5 soybean lines while after terrace construction, plots could only hold 4 soybean lines. However, terrace construction also reduced yields per unit area (630 kg ha^{-1} vs. 770 kg ha^{-1} without terraces). Most likely, the soil embankment brought unfertile, acid subsoil to the surface, which negatively affected crop performance. Reduced tillage did not significantly affect soybean yields when terraces were installed or *Calliandra* hedgerows were planted, but yields were significantly increased in plots without terraces and hedgerows. Planting of *Calliandra* hedgerows only decreased yields in plots without tillage and terrace construction.

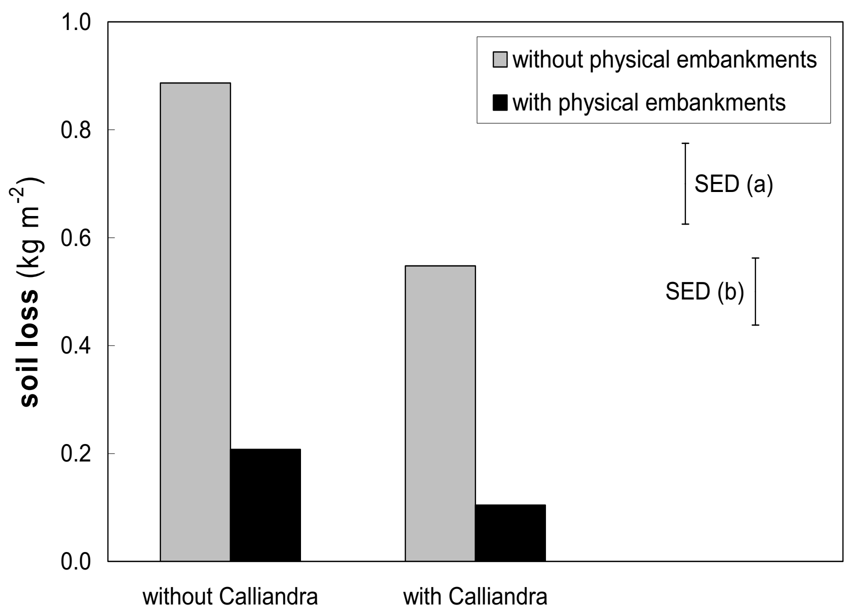

Figure 22: Soil loss during the first month after planting (2nd season) as affected by hedgerow planting and terrace construction; error bars represent SED, comparing (a) with and without terraces, and (b) with and without hedgerows

Soil erosion was significantly reduced by terrace construction and *Calliandra* hedgerow planting **(Figure 22)**; tillage management did not affect soil loss. During the first month after planting (2nd season), the soil loss amounted to almost 1 kg m^{-2}in plots without conservation measures, which approximates a loss of 1 mm of the soil profile. This soil loss was reduced by 80% in plots with physical embankments. *Calliandra* hedgerows were less effective in reducing soil erosion. *Calliandra* initially grows slowly and the hedgerows are at present not yet fully developed. Further measurements are required to assess the effectiveness in soil conservation in the longer term.

As a preliminary conclusion, terrace construction is most effective in the short-term to reduce soil erosion, but the reduction in surface area and upturning of subsoil considerably reduces crop yields. Planting *Calliandra* hedgerows has less influence on crop yield, but is also less effective in reducing soil erosion. Long-term effects on crop yield and soil stabilisation need to be assessed to appraise *Calliandra* hedgerow planting as an alternative to terrace construction.

Evaluation of hedgerow forages for erosion control in farmers' environment ("ERO-2")
Ten forage species (*Brachiaria brizantha*, *Brachiaria decumbens*, *Brachiaria ibrido*, *Brachiaria ruziziensis*, *Calliandra calothyrsus*, *Leucaena diversifolia*, *Penisetum purpureum*, *Setaria sphacelata*, *Tithonia diversifolia* and *Tripsacum laxum*) were established as hedgerows in 6 sites (Lurhala, Mwegerera, Luhihi, Kabamba, Cijingire and Mudaka). Measurements included survival rate and biomass accumulation, and slope and soil accumulation.

Farmers evaluated the forages about 10 months after establishment. The procedure used for forage evaluation was similar as for the legume germplasm evaluation. In each site, the male and female members of the association were separated and first defined their criteria for evaluation. They then visited the trial and specified positive and negative traits of each variety, and finally selected five forages which they scored according to their criteria.

Farmers evaluating different forages in Lurhala, Sud-Kivu.

The criteria defined by farmers primarily comprised the use of the biomass as a green manure, effective rooting (as an indicator for its capacity to contain the soil), use as a forage and production of high amounts of biomass **(Figure 23 a and b).**

These criteria were mentioned by at least 80% of the evaluating farmer groups. Other minor criteria included the potential for using in construction (mainly as roofing for houses), being non-competitive with crops (shading) and producing poles for climbing bean cultivation.

Farmers selected and scored the forages based on these criteria. *Tithonia*, *Tripsacum* and *Calliandra* were the most preferred forages, selected in the top 5 by 67, 75 and 92 % of the evaluating farmer groups, respectively. *Tithonia* and *Tripsacum* were generally ranked higher (average rank = 2) than *Calliandra* (average rank = 3). Farmers appraised *Tithonia* and *Setaria* as the most effective for soil erosion control, followed by *Calliandra*, *Tripsacum* and *Penisetum*.

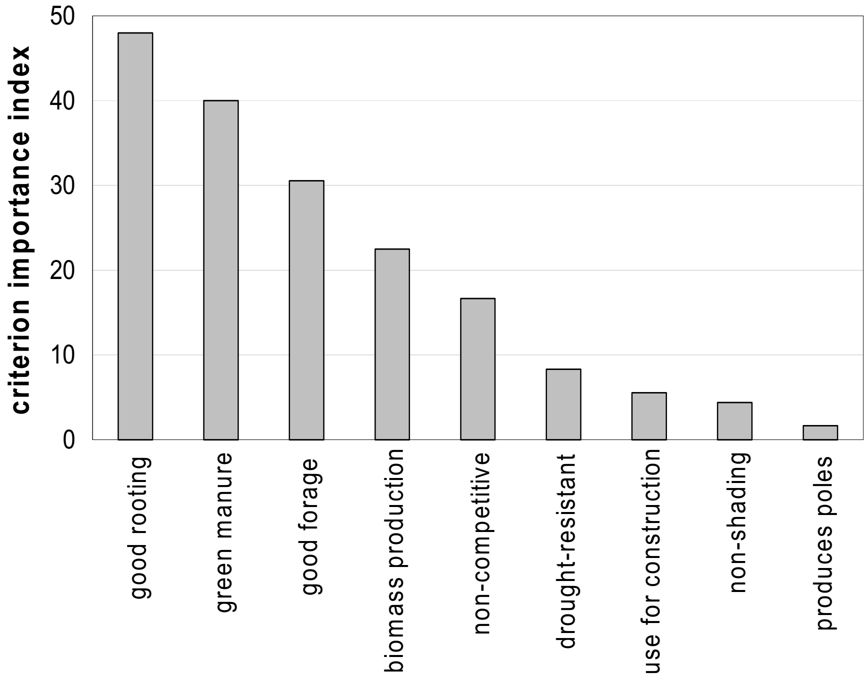

Figure 23a: Farmer-defined criteria for evaluation of forages

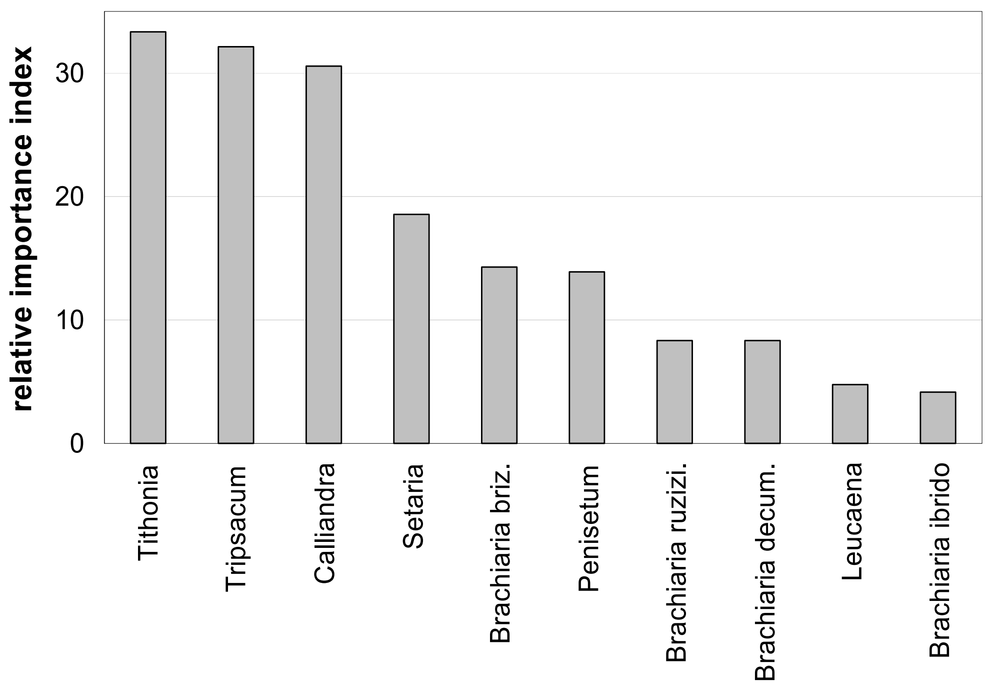

Figure 23b: Forage species selected by farmer groups; the relative importance index was calculated as the frequency of the criterion or forage species (%) divided by its average rank

Improved agronomy and soil fertility management in cassava-legume trials

In Bas-Congo, and to a lesser extent in Sud-Kivu, legumes are predominantly cultivated in association with cassava. Options for improved agronomic practices and nutrient management in these systems were discussed with partners and farmer groups. Three sets of demonstration trials were then installed, including options for improving productivity through (i) improved germplasm, (ii) alternative spacing, (iii) application of locally available green manures and/or fertilizer, (iv) reduced tillage, (v) planting alternative legume species, and (vi) planting climbing beans during the second season. The first set of trials was installed in April 2007 with two farmer associations in Bas-Congo (two sites, 3 replicates per site) and focuses on improved agronomic practices ("CAS-1"). The second set likewise focuses on improved agronomic practices and was installed in September 2007 with 3 farmer associations in 6 sites in the Kabamba action site in Sud-Kivu ("CAS-2"). The third set of trials focuses specifically on nutrient input management using green manures and/or fertilizer to improve cassava production, and was installed in April 2007 with two farmer associations in Bas-Congo (two sites, 3 replicates per site ("CAS-3). Specific measurements included legume biomass and grain production, cassava tuber production and tuber quality/tradability, and detailed labour assessments. Farmers evaluated the trial at different stages: firstly at peak biomass production of the legumes (2 months after planting), secondly after harvest of the legumes (4 months after planting), and finally at the cassava harvest (12 months after planting).

Biomass production in the traditional system was generally low (for example 2 t DM ha^{-1} in Nkamu, Bas-Congo; **(Figure 24).** Biomass production can be considerably increased by fertilizer application or replacing the traditional legume species (groundnut in Bas-Congo, beans in Sud-Kivu) by soybean. In Nkamu (Bas-Congo), biomass yield was three times higher for soybean than for groundnut. This has important implications for soil fertility management, as a biomass production of 6 t DM ha^{-1} may supply a net input of 30 – 40 kg N ha^{-1} (to be verified by BNF measurements), and entail significant rotational benefits for subsequent crops (to be verified in successive seasons).

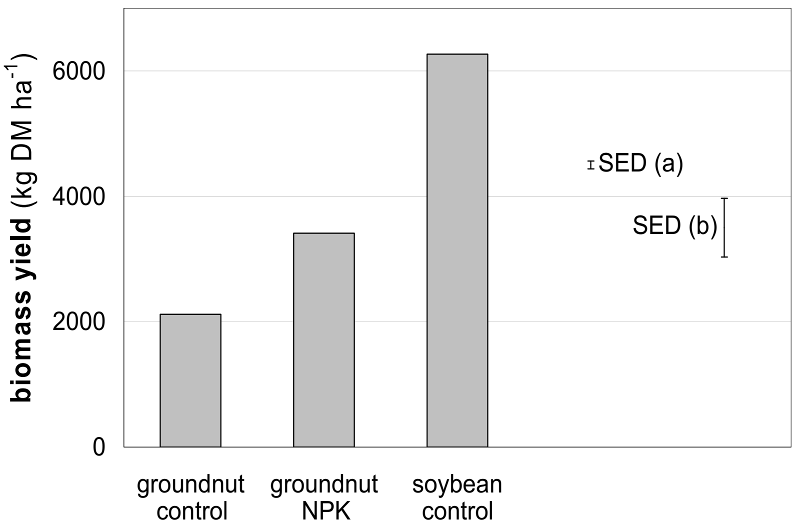

Figure 24: Biomass yield obtained for groundnut (with and without NPK applied at 100 kg ha^{-1}) and soybean grown in association with cassava in Nkamu, Bas-Congo, DRC; error bars represent SED for comparison of effects of NPK application (a) and legume species (b).

Legume grain yields can also be substantially increased using improved agronomic practices and fertilizer application. In Kabamba (Sud-Kivu), for example, pod yields for the traditional legume (beans) were increased by 50% using an alternative intercropping spacing that favours the legume; fertilizer application doubled yields compared to the traditional system **(Figure 25 a).** Soybean generally performed very well in association with cassava, when planted at a spacing of 2 × 0.5m, allowing sufficient space for 4 lines of soybean (400,000 plants per hectare) between cassava lines (10,000 plants per hectare).

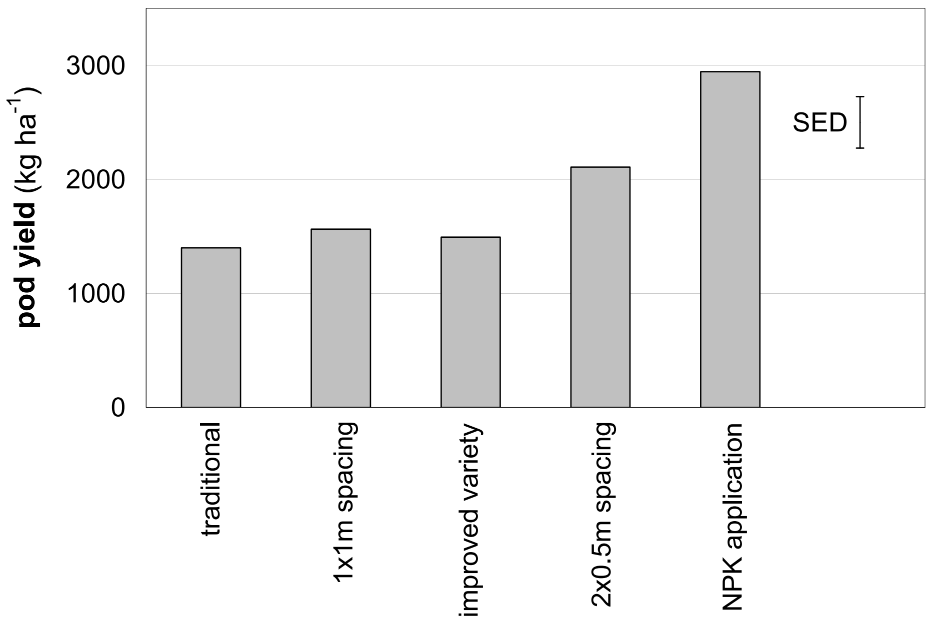

Figure 25a: Pod yields for common beans obtained by successively changing the spacing (1 × 1m), variety, spacing (2 × 0.5m) and applying NPK at 100 kg ha^{-1} in Kabamba, Sud-Kivu, DRC.

Farmers have currently evaluated the trial twice, at podding and harvest of the legume. At the podding stage, farmers primarily evaluated based on the production of biomass, the number of pods or flowers, the lustre (greenness) of the leaves, and the presence of diseases. Farmers particularly preferred the option with cassava planted at 2 × 0.5m and intercropped with soybean (and to a lesser extent with an improved bean variety) as well as the option with NPK application.

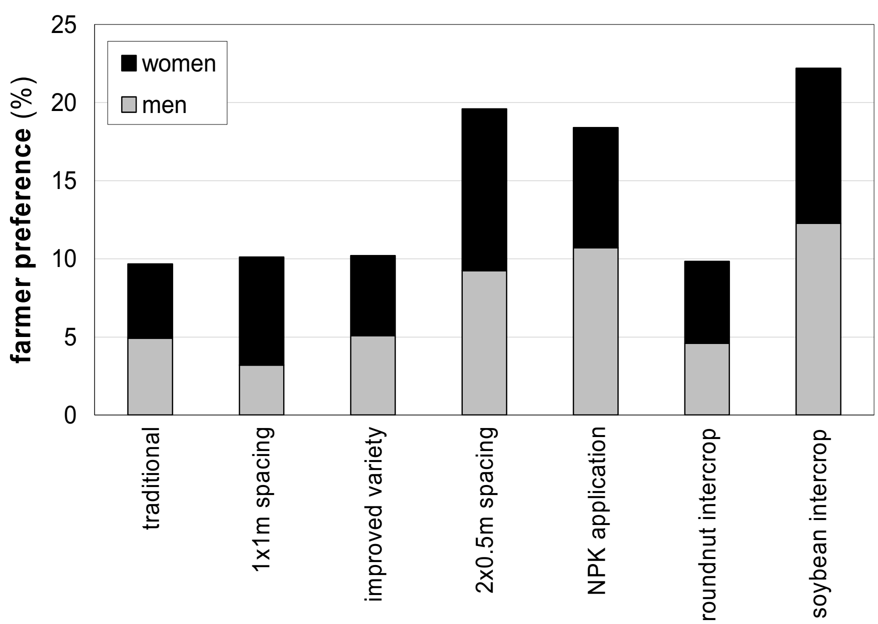

Figure 25b: Farmer preference of improved agronomic practices demonstrated in Kabamba, Sud-Kivu, as compared to the traditional cassava-legume intercropping system by successively changing the spacing (1 × 1m), variety, spacing (2 × 0.5m), applying NPK at 100 kg ha^{-1} and replacing the common legume (beans) for groundnut or soybean.

These trials have attracted large interest by the farmer associations and neighbouring farming communities. At present (season 2008 B), this activity has proceeded into an adaptation phase. Individual members of farmer associations have been given access to improved legume varieties, cassava cuttings and fertilizer, and have been trained to test and adapt the demonstrated options in their own fields. A demonstration trial on improved cassava-legume intercropping in Kabamba, Sud-Kivu, DRC.

Output target 2009

- ***The potential for occurrence of positive interactions between organic and mineral inputs is evaluated for the most common cropping systems in each mandate area***

Published work

Bationo[1], A., Vanlauwe[1], B., Kihara[1], J. and Kimetu[2], J. (2007) Soil organic carbon dynamics, functions and management in West African agro-ecosystems. In: Bationo, A, Vanlauwe, B., Kihara, J. and Kimetu, J. (eds). Advances in integrated soil fertility management in sub-Saharan Africa: Agriculture Systems 94: 13 - 25

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Abstract: Soil fertility depletion (mainly N, P and carbon) has been described as the single most important constraint to food security in West Africa. Over half of the African population is rural and directly dependent on locally grown crops.

Further, 28% of the population is chronically hungry and over half of people are living on less than US$ 1 per day as a result of soil fertility depletion. Soil organic carbon (SOC) is simultaneously a source and sinks for nutrients and plays a vital role in soil fertility maintenance. In most parts of West Africa agro-ecosystems (except the forest zone), the soils are inherently low in SOC. The low SOC content is due to the low shoot and root growth of crops and natural vegetation, the rapid turnover rates of organic material as a result of high soil temperatures and fauna activity particularly termites and the low soil clay content. With kaolinite as the main clay type, the cation exchange capacity of the soils in this region, often less that 1 cmol kg^{-1}, depends heavily on the SOC. There is a rapid decline of SOC levels with continuous cultivation. For the sandy soils, average annual losses may be as high as 4.7% whereas with sandy loam soils, losses are lower, with an average of 2%. To maintain food production for a rapidly growing population application of mineral fertilizers and the effective recycling of organic amendments such as crop residues and manures are essential. Crop residue application as surface mulch can play an important role in the maintenance of SOC levels and productivity through increasing recycling of mineral nutrients, increasing fertilizer use efficiency, and improving soil physical and chemical properties and decreasing soil erosion. However, organic materials available for mulching are scarce due to low overall production levels of biomass in the region as well as their competitive use as fodder, construction material and cooking fuel. Animal manure has similar role as residue mulching for the maintenance of soil productivity but it will require between 10 and 40 ha of dry season grazing and between 3 and 10 ha of rangeland of wet season grazing to maintain yields on one hectare of cropland. The potential of manure to maintain SOC levels and maintain crop production is thus limited by the number of animals and the size and quality of the rangeland. The potential livestock transfer of nutrients in West Africa is 2.5 kg N and 0.6 kg P per hectare of cropland.

Scarcity of organic matter calls for alternative options to increase its availability for improvement of SOC stock. Firstly, the application of mineral fertilizer is a prerequisite for more crop residues at the farm level and the maintenance of soil organic carbon in West African agro-ecosystems and therefore most research should focus on the improvement of nutrient use efficiency in order to offer to the smallholder farmers cost-effective mineral fertilizer recommendations. Secondly, recent success story on increasing crop production and SOC at the farm level is the use of the dual purpose grain legumes having ability to derive a large proportion of their N from biological N fixation, a low N harvest and substantial production of both grain and biomass. Legume residues can be used for improvement of soil organic carbon through litter fall, or for feeding livestock with the resultant manure being returned to the crop fields.In the decision support system for organic matter management, recommendations for appropriate use of organic material was made based on their resource quality, expressed as a function of N, polyphenol and lignin content. High quality organic materials release a high proportion of their N quickly. The impact of organic resource quality on SOC is less clear. Low quality organic resources contain substantial amounts of soluble polyphenols and lignins that may affect the longer-term decomposition dynamics and contribute to the build up of SOC. Future research needs to focus more on whether the organic resource quality concept is also useful for predicting different degrees of stabilization of applied organic C in one or more of the organic matter pools.

Work in progress

Effects of soil fertility management practices on soil bio- physical properties: a case for murewa smallholder farming.

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Soil fetility varies considerably in smallholder farming system. Several studies have been undertaken to assess variability i soil chemical properties within and across farms, and its implication on nutrient use efficiencies homefields (HFs) closest to homesteads receive large additions of manure and tend to be more fertile than outfields (OFs) further away. The present analyzed this influence of differential manure application and on SOC, bulk density, aggregate stability, aggregate protected carbon, moisture retention and microbial biomass. In experiments established on HFs and OFs on a sandy and clay soils to assess nutrient use efficiencies, 100 kg ha^{-1} N was applied in combination with three rates of manure (5, 15 and 25 t ha^{-1}) over a 5 year period. SOC significantly ($P < 0.01$) increased with manure application across all the fields. The bulk density was significantly lower on the HFs than OFs, and bulk density was reduced significantly with addition of 15 t ha^{-1} and 25 t ha^{-1} manure. Water stable aggregates and aggregate protected carbon increased with increase in manure applied. Moisture retention was significantly ($P< 0.01$) greater under 15 t ha^{-1} and 25 t ha^{-1} manure application rates on both soils while across fields it was significantly ($P< 0.05$) greater on homefields under low suctions. Microbial biomass carbon increased from around 0.0083- 0.038 g kg^{-1} soil and 0.0057- 0.026 g kg^{-1} soil on the homefields and outfields respectively from the control to 25 t ha^{-1} manure treatment but across the fields it did not significantly ($P< 0.05$) vary with farmer management. Maize yields for the 2006-2007 season were significantly increased with increasing manure application and on both the HF and the OF. These yield increases can be attributed to effects of manure on chemical, biological and physical properties of soils.

Output target 2009

- ***Throughout the Institute project life, new questions generated in the evaluation efforts of the different target outputs are addressed and fed back to these evaluation activities***

Output target 2010

- ***Cereal – legume systems with improved germplasm as entry point tested, adapted and validates to farmer conditions in savanna areas***

Published work

Zingore [12], S., Murwira [1], H.K., Delve [1], R.J., Giller [2], K.E. Soil type, management history and current resource allocation: Three dimensions regulating variability in crop productivity on African smallholder farms. Field Crops Research, 101: 296-305
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Abstract: Soil fertility varies markedly within and between African smallholder farms, both as a consequence of inherent factors and differential management. Fields closest to homesteads (homefields) typically receive most nutrients and are more fertile than outlying fields (outfields), with implications for crop production and nutrient use efficiencies. Maize yields following application of 100 kg N ha^{-1} and different rates and sources of P were assessed on homefields and outfields of smallholder farms in Zimbabwe. Soil organic carbon, available P and exchangeable bases were greater on the homefields than outfields. In each of three experimental seasons, maize yields in homefield control plots were greater than in the outfields of farms on a granitic sandy and a red-clay soil. Application of mineral N significantly increased maize yields on homefields in the first season (2.1–3.0 t ha^{-1} on the clay soil and 1.0–1.5 t ha^{-1} on the sandy soil) but the effects of N alone were not significant on the outfields due to other yield-limiting factors. Greatest yields of about 6 t ha^{-1} were achieved on the clayey homefield with 100 kg N ha^{-1} and 30 kg P ha^{-1} applied as single super phosphate (SSP). Manure application gave greater yields (3–4 t ha^{-1}) than SSP (2–3 t ha^{-1}) in the sandy homefield and in the clayey outfield. Maize did not respond significantly to N, dolomitic lime, manure and P on the sandy outfield in the first and second seasons. In the third season, manure application (17 t manure ha^{-1} $year^{-1}$) on the sandy outfield did result in a significant response in grain yields. Apparent P recovery in the first season was 55–65% when P was applied at 10 kg ha!1 on the clayey homefield (SSP), clayey outfield (SSP and manure) and sandy homefield (manure) with apparent P recovery less than 40% when P was applied at 30 kg ha^{-1}. On the sandy outfield, P recovery was initially poor (<20%), but increased in the successive seasons with manure application. In a second experiment, less than 60 kg N ha^{-1} was required to attain at least 90% of the maximum yields of 2–3 t ha^{-1} on the sandy homefield and clayey outfield. N use efficiency varied from >50 kg grain kg^{-1} N on the infields, to less than 5 kg grain kg^{-1} N on the sandy outfields. Apparent N recovery efficiency by maize was greatest at small N application rates with P applied. We conclude that blanket fertilizer recommendations are of limited relevance for heterogeneous smallholder farms. Targeted application of mineral fertilizers and manure according to soil type and past management of fields is imperative for improving crop yields and nutrient use efficiencies.

Kihara[1], J., Kimetu[2], J.M., Vanlauwe[1], B., Bationo[1], A., Waswa[1], B. and Mukalama[1], J.
Optimising crop productivity in legume-cereal rotations through nitrogen and phosphorus management in western Kenya. In: Advances in integrated soil fertility management in sub Saharan Africa: challenges and opportunities, (eds) Bationo, A., Waswa, B., Kihara, J. and Kimetu, J. Challenges and Opportunities, 493-501
[1]*CIAT-TSBF, Kenya;* [2]*Cornell University, USA;*
Abstract: Combined application of organic resources and mineral inputs is integral to sustainable soil fertility management but in-situ production of adequate organic matter is often limited by P availability. An experiment was set up at Nyabeda in Western Kenya aimed at (1) quantifying the contribution of herbaceous and grain legumes to nitrogen supply in a cereal-legume rotation system and (2) quantifying the impact of targeting phosphorus (P) to certain phases of the rotation on overall maize grain yield. In this split-split plot experiment, *Mucuna pruriens* was used as the herbaceous legume while soybean was used as the grain legume. Results obtained in the two seasons of the study indicated that the use of either mucuna or soybean as previous crop significantly increased maize grain yield with or without the addition of nitrogen fertilizer. More than 5 tons ha^{-1} of maize grain yield was realised in season two following the addition of phosphorus fertilizer at both season one and season two compared to about 3 tons ha^{-1} of maize grain yields obtained when no P was added. It could be concluded that in this region, the addition of P fertilizer is an integral management option to ensure optimal utilization of the nitrogen fixed by the legume crop. Using P during the legume season may be sufficient to supply P requirements to the succeeding cereal crop. Also, applying P to the mucuna or soybean legume crop was not any different from applying it both to the legume and cereal crops indicating that farmers can save labour and cash by applying P only to the legume. The good performance of maize planted after mucuna was an indication that mucuna could be used by farmers in the region as an N source (Nitrogen Fertilizer Equivalency (NFE) >100 kg N ha^{-1}) thus reducing cost of buying N fertilizers. Although soybean showed a lower NFE of 40 kg N ha^{-1}, it had higher economic benefits and could thus be more acceptable to the farmers. These findings could be confirmed by using more than two cereals and legume rotation cycles

Mucheru-Muna[1], M., Mugendi[1], D., Kung'u[1], J., Mugwe[2], J. and Bationo[3], A.
(2007) Effects of organic and mineral fertilizer inputs on maize yield and soil chemical properties in a maize cropping system in Meru South District, Kenya. In: A. Bationo (eds.), Advances in Integrated Soil Fertility Research in Sub-Saharan Africa: Journal: Agroforestry Systems 69:189–197
[1]*Kenyatta University, Kenya;* [2]*KEFRI, Kenya;* [3]*CIAT-TSBF, Kenya*
Abstract: Soil nutrient depletion as a result of continuous cultivation of soils without adequate addition of external inputs is a major challenge in the highlands of Kenya. An experiment was set up in Meru South District, Kenya in 2000 to investigate the effects of different soil-incorporated organic (manure, Tithonia diversifolia, Calliandra calothyrsus, Leucaena leucocephala) and mineral fertilizer inputs on maize yield, and soil chemical properties over seven seasons. On average, tithonia treatments (with or without half recommended rate of mineral fertilizer) gave the highest grain yield (5.5 and 5.4 Mg ha^{-1} respectively) while the control treatment gave the lowest yield (1.5 Mg ha^{-1}). After 2 years of trial implementation, total soil carbon and nitrogen contents were improved with the application of organic residues, and manure in particular improved soil calcium content.

Results of the economic analysis indicated that on average across the seven seasons, tithonia with half recommended rate of mineral fertilizer treatment recorded the highest net benefit (USD 787 ha^{-1}) while the control recorded the lowest (USD 272 ha^{-1}). However, returns to labor or benefit-cost ratios were in most cases not significantly improved when organic materials were used.

Bado[1], B.V., Bationo[2], A., Lompo[3], F., Cescas[4], M.P. and Sedogo[3], M.P. (2007) Mineral fertilizers, organic amendments and crop rotation managements for soil fertility maintenance in the Guinean zone of Burkina Faso (West Africa) In: A. Bationo (eds.), Advances in Integrated Soil Fertility Research in Sub-Saharan Africa: Challenges and Opportunities, 165–171 Springer.

[1]INERA, Burkina Faso; [2]CIAT-TSBF, Kenya; [3]INERA, Burkina Faso; 4 Département des Sols et Génie Agroalimentaire (FSSA), Canada

Abstract: The effects of cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogea*) on succeeding sorghum yields, soil mineral nitrogen and N recoveries were studied during three years (2000 to 2002) in a weakly acid Ultisol of the agronomic research station of Farakô-Ba located in the Guinean zone of Burkina Faso. Afield agronomic experiment with a factorial 3×4 design of three crop rotations (cowpea-sorghum, groundnut-sorghum and sorghum-sorghum) as first factor and four fertilizer treatments (PK fertilizer, NPK, NPK+ Manure and control) as second factor in a split plot arrangement with four replications. Highest yields were obtained when sorghum was rotated with legumes while lowest yields were obtained in mono cropping of sorghum. Compared to mono cropping, sorghum could produced 2.9 and 3.1 times more grain yields when it was rotated with groundnut or cowpea respectively. A better use of fertilizer N was observed in legume sorghum rotations. In continuous sorghum, fertilizer N use efficiency (NUE) was 20%. But in Cowpea-Sorghum and Groundnut-Sorghum rotations, NUEs were 28 and 37% respectively. Legume-sorghum rotations increased sol mineral nitrogen. The soils of legume-sorghum rotations provided more nitrogen to succeeding sorghum compared to mono cropping of sorghum and the highest total N uptake by sorghum was observed in legume-sorghum rotations

Tabo[1], R., Bationo[2], A., Gerard[1], B., Ndjeunga[1], J., Marchal[3], D., Amadou[3], B., Annou[4], M.G., Sogodogo[5], D., Taonda[6], J.S., Hassane[1], O., Diallo[1], M.K. and Koala[1], S. (2007) Improving cereal productivity and farmers' income using a strategic application of fertilizers in West Africa. In: A. Bationo (eds.), Advances in Integrated Soil Fertility Research in Sub-Saharan Africa: Challenges and Opportunities, 192–199 Springer.

[1]ICRISAT, Niger; [2]CIAT- TSBF, Kenya; [3]FAO, Niger; [4]INRAN, Niger; [5]IER, Mali; [6]INERA, Burkina Faso

Abstract: In the past two years, ICRISAT, in collaboration with other International Agricultural Research Centres, National Agricultural Research and Extension Systems, has been evaluating and promoting point or hill application of fertilizer along with "Warrantage" in three West African countries, namely, Burkina Faso, Mali and Niger. The hill application of fertilizers consists of applying small doses of fertilizer in the planting hills of millet and sorghum. The combination of strategic hill application of fertilizer with complementary institutional and market linkages, through an inventory credit system (known as "Warrantage") offers a good opportunity to improve crop productivity and farmers' incomes.

Results from the two year on-farm trials showed that, on average, in all the three countries, grain yields of millet and sorghum were greater by 44 to 120% while incomes of farmers increased by 52 to 134% when using hill application of fertilizer than with the earlier recommended fertilizer broadcasting methods and farmers' practice. Substantial net profits were obtained by farmers using "Warrantage". Farmers' access to credit and inputs was improved substantially through the "Warrantage" system. The technology has reached up to 12650 farm households in the three countries and efforts are in progress to further scale-up and out the technology to wider geographical areas.

Mugendi[1], D., Mucheru-Muna[1], M., Mugwe[2], J., Kung'u[1], J. and Bationo[3], A. (2007) Improving food production using 'best bet' soil fertility technologies in the Central highlands of Kenya. In: A. Bationo (eds.), Advances in Integrated Soil Fertility Research in Sub-Saharan Africa: Challenges and Opportunities, 329–335 Springer.
[1]Kenyatta University, Kenya; [2]KenyaForestry Research Institute, Kenya; [3] CIAT-TSBF, Kenya
Abstract: Declining crop productivity is a major challenge facing smallholder farmers in central highlands of Kenya. This decline is caused by continuous cultivation of soils without adequate addition of external inputs in form of manures and fertilizers. With this background, an on-station trial was initiated at Embu in 1992 to evaluate the feasibility of using two leguminous shrubs; *Calliandra calothyrsus* and *Leucaena leucocephala* for improving food production. In 2000, an off-station farmers' participatory trial aimed at offering farmers soil enhancing technologies for replenishing soil fertility was established in Meru South District. The results from the Embu on-station trial indicate that, over the 11 years of study, calliandra and leucaena biomass transfer with half recommended rate of inorganic fertilizer treatments gave the best average maize grain yields of 3.3 Mg ha^{-1}. Treatment where calliandra was alley cropped with maize but the prunings removed recorded the lowest maize yield of 1.2 Mg ha^{-1}. Treatments with calliandra and leucana biomass transfer had similar yields but treatments that were alley cropped with leucaena did better than those that were alley cropped with calliandra. On the other hand, results from the off-station trial in Meru South indicate that, on average, across the seven seasons, sole tithonia gave the highest maize grain yield followed closely by tithonia with half recommended rate of inorganic fertilizer with 6.4 and 6.3 Mg ha^{-1} respectively. Control gave the lowest yield of 2.2 Mg ha^{-1} across the seasons. On average, integration of organic an inorganic sources of nutrients gave higher yields compared to all the other treatments.

Kimani[1], S.K., Esilaba[1], A.O., Odera[1], M.M., Kimenye[2], L., Vanlauwe[3], B. and Bationo[3], A. (2007) Effects of organic and mineral sources of nutrients on maize yields in three districts of central Kenya. In: A. Bationo (eds.), Advances in Integrated Soil Fertility Research in Sub-Saharan Africa: Challenges and Opportunities, 336–340 Springer.
[1]*Kenya Agricultural Research Institute, Kenya.* [2]*Department of Agricultural Economics, University of Nairobi, Kenya.* [3]*CIAT-TSBF, Kenya.*
Abstract: Trials were set up in three districts of central Kenya to evaluate organic and mineral sources of nutrients and their effects on maize yields. The experiments were set up during the long rains 2004 with fifteen different soil fertility management treatments. The treatments included cattle manure, green manures, maize stover, *Tithonia*, and mineral fertilizer. The test crop was maize (*Zea mays*), intercropped with beans (*Phaseolus vulgaris*). The experimental design was a Randomized Complete Block with three replicates.

At final harvest at maturity, grain yield data were recorded. In general the yields were low (≤1t ha^{-1}) in the unfertilized control, in plots intercropped with green manure cover crops, and where maize stover alone was applied. In Kirinyaga, and Maragwa, the highest maize grain yields (6.5t ha^{-1}) were obtained when manure was combined with mineral fertilizer. The responses were not as clear in the Kiambu site, possibly due to soil acidity at the site. There were no significant difference (p=0.05) in grain yields between the green manure cover crops (0.4–1.5t ha^{-1}), maize stover (0.3–0.9t ha^{-1}) and the unfertilized control (0.4–1t ha^{-1}) across treatments and sites during this first season. The work confirms the efficiency of combining mineral sources of nutrients with organic inputs.

Miriti[1], J.M., Esilaba[2], A.O., Bationo[3], A., Cheruiyot[2], H., Kihumba[1], J. and Thuranira[4], E.G. (2007) Tied-ridging and integrated nutrient management options for sustainable crop production in semi-arid eastern Kenya. In: A. Bationo (eds.) Advances in Integrated Soil Fertility Research in Sub-Saharan Africa: Challenges and Opportunities, 435–441 © 2007 Springer.

[1]National Agricultural Research Centre, Kenya Agricultural Research Institute, Kenya; [2]Desert Margins Programme, Kenya Agricultural Research Institute, Kenya. [3]CIAT- TSBF, Kenya; [4]National Agricultural Research Laboratories, Kenya Agricultural Research Institute, Kenya.

Abstract: A field experiment was conducted for two seasons at Emali, Makueni District in Eastern Kenya to compare the effect of tied ridging and integrated nutrient management practices on the yield of rainfed maize (*Zeamays L.*) and cowpeas (*Vigna unguiculata L.*). The main treatments were flat bed (FB, traditional farmers' practice) and tied ridging (TR) as main plots. The manure and fertilizers were farmyard manure (FYM, goat manure at 0 and 5 t ha^{-1}) in a factorial combination with nitrogen (N fertilizer at 0, 40, 80 and 120 kg N ha^{-1}) and P fertilizer at 0 and 40 kg P ha^{-1} as the subplots in a split-plot treatment arrangement of a randomized complete block design (RCBD). Results from maize yield data in the continuous maize cropping systems indicate that maize stover was significantly (P≤0.05) increased by the application of 5 t ha^{-1} of manure in both seasons. Tied ridges, manure and fertilizer did not affect grain yields in the first season. However, mean grain yields obtained in plots with tied-ridges and manure were higher by 11% and 14% compared to plots without tied ridges and manure respectively. There was a significant interaction between manure and nitrogen which gave higher stover yields in the 2003 long rains season. Under the cowpeas–maize intercropping system, tied ridges and manure application did not have a significant effect on maize yields in both seasons. Application of nitrogen significantly (P≤0.05) increased maize stover by 29% and TDM yields by 50% in first and second season respectively when compared with treatments without nitrogen. Nitrogen application also increased cowpea stem and TDM yields by 57% and 45% respectively in the second season. Cowpea yields were not affected by tied-ridges in both seasons. There was significant effects of manure, nitrogen, manure * nitrogen and tied ridging * nitrogen interactions on cowpea stem and TDM in 2003 short rains season. In general, the combination of tie-ridges with manure or nitrogen gave higher maize and cowpea yields than when these factors are applied alone. These preliminary results indicate that tied ridging in combination with integrated nutrient management has the potential to improve crop production in semi-arid eastern Kenya.

Tabu[1], I.M., Bationo[2], A., Obura[1], R.K. and Masinde[1], J.K. (2007) Effect of Rock Phosphate, Lime and Green Manure on Growth and Yield of Maize in a Non Productive Niche of a Rhodic Ferralsol in Farmer's Fields. In: A. Bationo (eds.), Advances in Integrated Soil Fertility Research in Sub-Saharan Africa: Challenges and Opportunities, 449–456 Springer.

[1]Department of Crops, Horticulture and Crop Sciences, Egerton University, Kenya; [2]CIAT-TSBF, Kenya; [3]Department of Soil Science, Egerton University, Kenya,

Abstract: *Ferralsol* and *Acrisol* soil types important for maize production in Western Kenya have low pH, phosphorus (P) and organic matter plus high levels of Al and Fe oxides that fix P. Minjingu rock phosphate (MRP), lime and green manure (*Tithonia*) that are cheap and locally available are recommended for use. The low solubility of MRP when directly applied and unavailability of adequate organic materials limits their use. An experiment was carried out in farmers' field to determine the interactive effect of combining MRP and *Tithonia* or lime in a degraded patch of *Ferralsol* soil in Western Kenya. The treatments; ±MRP, ±lime, ±*Tithonia*, +Triple superphosphate (TSP) and their combinations were applied to maize in (4×5) m^2 plots. The field layout was in a completely randomized block design replicated four times. Plant height (eight weeks after emergence) and leaf number showed a significant interactive effect between: TSP×*Tithonia* ($P \leq 0.0001$), TSP×Lime ($P \leq 0.001$), MRP×*Tithonia* ($P \leq 0.05$), *Tithonia*×TSP×Lime ($P \leq 0.005$). Leaf area index (m^2 leaf m^{-2}) was similarly was significantly affected by TSP ($P \leq 0.0001$), lime ($P \leq 0.05$), lime×TSP ($P \leq 0.0002$) and TSP×*Tithonia* ($P \leq 0.0001$) and lime×*Tithonia*×TSP ($P \leq 0.05$). The significant treatments also affected were similarly observed in grain yield (t/ha) as TSP (2.5 t/ha), MRP (1.0 t/ha), lime×TSP (2.5 t/ha), TSP×*Tithonia* (2.9 t ha^{-1}), Tithonia×TSP×lime (2.4). Hence combining TSP or MRP with *Tithonia* may be used to alleviate multiple problems in the degraded patches of *Ferralsols*

Kihara[1], J., Kimetu[1], J.M., Vanlauwe[1], B., Bationo[1], A., Waswa[1], B. and Mukalama[1], J. (2007) Optimising crop productivity in legume-cereal rotations through nitrogen and phosphorus management in western Kenya. In: A. Bationo (eds.), Advances in Integrated Soil Fertility Research in Sub-Saharan Africa: Challenges and Opportunities, 493–501 Springer.

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Abstract: Combined application of organic resources and mineral inputs is integral to sustainable soil fertility management but in-situ production of adequate organic matter is often limited by P availability. An experiment was set up at Nyabeda in Western Kenya aimed at (1) quantifying the contribution of herbaceous and grain legumes to nitrogen supply in a cereal-legume rotation system and (2) quantifying the impact of targeting phosphorus (P) to certain phases of the rotation on overall maize grain yield. In this split-split plot experiment, *Mucuna pruriens* was used as the herbaceous legume while soybean was used as the grain legume. Results obtained in the two seasons of the study indicated that the use of either mucuna or soybean as previous crop significantly increased maize grain yield with or without the addition of nitrogen fertilizer. More than 5 tons ha^{-1} of maize grain yield was realised in season two following the addition of phosphorus fertilizer at both season one and season two compared to about 3 tons ha^{-1} of maize grain yields obtained when no P was added. It could be concluded that in this region, the addition of P fertilizer is an integral management option to ensure optimal utilization of the nitrogen fixed by the legume crop.

Using P during the legume season may be sufficient to supply P requirements to the succeeding cereal crop. Also, applying P to the mucuna or soybean legume crop was not any different from applying it both to the legume and cereal crops indicating that farmers can save labour and cash by applying P only to the legume. The good performance of maize planted after mucuna was an indication that mucuna could be used by farmers in the region as an N source (Nitrogen Fertilizer Equivalency (NFE) >100 kg N ha^{-1}) thus reducing cost of buying N fertilizers. Although soybean showed a lower NFE of 40 kg N ha^{-1}, it had higher economic benefits and could thus be more acceptable to the farmers. These findings could be confirmed by using more than two cereals and legume rotation cycles

Adamou[1], A., Bationo[2], A., Tabo[1], R. and Koala[1], S. (2007) Improving soil fertility through the use of organic and inorganic plant nutrient and crop rotation in Niger. In: A. Bationo (eds.), Advances in Integrated Soil Fertility Research in Sub-Saharan Africa: Challenges and Opportunities, 589–598 Springer.

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

Kaya[1], B. Niang[2], A. Tabo[3], R. and Bationo[4], A. (2007) Performance evaluation of various agroforestry species used in short duration improved fallows to enhance soil fertility and sorghum yields in Mali. In: A. Bationo (eds.), Advances in Integrated Soil Fertility Research in Sub-Saharan Africa: Challenges and Opportunities, 547–556 Springer.

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Abstract: The general soil fertility and crop yield decline constraints have guided the Malian agricultural research institute (Institut d_ Economie Rurale, IER), the Sahel Program of theWorld Agroforestry Centre (ICRAF) and the International Crops Research Institute for the Semi Arid

Tropics (ICRISAT) to join efforts and undertake research activities aimed at mitigating the constraints in Mali. Thus, from the year 2000, 14 different trees and shrubs are being tested in improved fallow systems to find which ones perform best to replenish soils and improve crop yields. The results have (i) identified most suited species for 1 or 2 yr improved fallows, (ii) determined their impact on sorghum grain yields and (iii) documented the remnant effects of their impact on soil fertility and crop yields. Some species (*Indigofera astragalina*, *Crotalaria ochroleuca*, *Crotalaria agatiflora*, *Crotalaria retusa*, *Crotalaria goreensis*, *Crotalaria paulina* et *Tephrosia vogelii*) could not survive more than 1 year the Samanko conditions. Among them, *C. agatiflora* (1944, 1141 and 741 kg sorghum grain yields ha−1 respectively in years 1, 2 and 3 after cultivation) and *I. Astragalina* (1343, 1301 and 393 kg sorghum grain yields ha−1 respectively in years 1, 2 and 3 after cultivation) would be the best candidates for 1-yr improved fallows. Others *Tephrosia* candida, *Sesbania sesban* (Lery, Gache, Kibwezi and Kakamega provenances), *Cassia sieberiana* and *Cajanus cajan* have completed 2-yr duration improved fallows. In 2002, the first year of cultivation, it was the Kenyan provenances of *Sesbania sesban* which performed best with sorghum grain yields over 2 t ha−1. A year later, 2003, there has been a general decrease in crop yield. Again, the Kenyan provenances of *S. seban*, with yields 40% lower than the first year of cultivation, were the worst affected by this decrease. No significant changes were observed in the traditionally tested chemical soil parameters. In conclusion, *C. agatiflora*, *I. astragalina* and the Kenyan provenances of *S. sesban* are well-adapted species for 1-yr improved fallow systems in the Samanko, Mali, conditions

Completed Work

Integrated management of Striga hermonthica, stemborers, and declining soil fertility in Western Kenya. Field Crops Research, In Press.

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[1]CIAT-TSBF, Kenya; [2]CIMMYT, Kenya; [3]Maseno University, Kenya; [4]Rothamsted Research, UK; [5]ICIPE, Kenya
Striga hermonthica (Delile) Benth., stemborers, and declining soil fertility are serious threats to sustainable food production in the Lake Victoria zone of Kenya. To address these constraints, promising integrated crop management technologies were evaluated, using a multi-locational design in four sub-locations in Siaya and Vihiga district (western Kenya) for six cropping seasons. Technologies evaluated consisted of the traditional maize (*Zea mays* L.) –bean (*Phaseolus vulgaris* L.) intercrop, maize – *Desmodium (Desmodium uncinatum* (Jacq.) DC.) push-pull intercrop, *Crotalaria* (*Crotalaria ochroleuca* G. Don) – maize rotation, and soybean (*Glycine max* (L.) Merr) – maize rotation. Within each of these systems, imazapyr-coated herbicide-resistant maize (IR-maize) and fertilizer were super-imposed as sub-plot factors. The push-pull system was observed to significantly reduce *Striga* emergence and stemborer damage from the second season onwards. IR-maize reduced and delayed *Striga* emergence from the first cropping season. Differences in *Striga* emergence and stemborer damage between the other systems were not significantly different. After five cropping seasons, the *Striga* seedbank was significantly higher in the maize-bean intercrop system than in the push-pull system under both maize varieties while the rotational systems had intermediate values not different from the day zero values. Under IR-maize, the *Striga* seed bank was significantly lower than under local maize for all cropping systems. Maize yields varied between seasons, districts, and cropping systems.

Yields in the push-pull system were higher than in the maize-bean intercrop after two seasons and in absence of mid-season drought stress. Both maize and soybean responded significantly to fertilizer application for both districts and for most seasons. The various interventions did not substantially affect various soil fertility-related parameters after five seasons. In the short term, IR-maize integrated in a push-pull system is the most promising options to reduce Striga while the rotational systems may need a longer timeframe to reduce the Striga seedbank. Finally, farmer-led evaluation of the various technologies will determine which of those is really most acceptable under the prevailing farming conditions.

Evaluation of the potential of arbuscular mycorrhizal fungi to enhance the initial growth of tissue culture bananas: B. Vanlauwe[1], N. Sanginga[1], E. Kahangi[2] T. Losenge[2], D. Odee[3], A. Elsen[4], and J. M. Jefwa[1],

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Characterization of banana farms was implemented in the major banana growing region in Maragua district, Kenya. Banana is the leading cash crop in Maragua, Kenya and the major production constraints are access to credit, soil fertility, water and to some extent pests and diseases. Soil fertility interventions consisted of application of manure although in limited supply and some application of inorganic fertilizer planting. The use of inorganic fertilizer was hampered by farmer perception on negative effects on post harvest quality of bananas. Farmer's wealth category affected management of banana plantations and subsequent yield, soil fertility levels, the prevalence of pests and diseases and subsequently the sale of bananas.

There is inadequate information on fertilizer recommendations in banana systems. To generate information that would enable farmers to adopt inorganic fertilizer, a trial was established in Maragua. It was evident that fertilizer (N, P, k, S, b, Mg, Zn, and Mo) was crucial for banana production. Lack of application of fertilizer delayed flowering, maturity and also reduced yield. Banana yield in plots full of application of fertilizer ranged from 25 t ha^{-1} – 33 t ha^{-1} compared to control yield of less than 8 t ha^{-1}. Omission of secondary macro and micro-nutrients reduced the chlorophyll content of banana leaves. Fertilizer affected specific banana ripening characteristics. Chlorophyll a, titrable acids and ascorbic acids responded most to fertilizer treatment.

Establishment of tissue culture bananas is paramount to sustain yields in banana plantations. This could be enhanced by Arbuscular Mycorrhizal Fungi (AMF). AMF inoculation of tissue culture bananas enhanced growth and nutrient uptake in bananas through AMF species were highly specific. Three *Glomus* species associated with bananas and enhanced both growth and nutrient uptake but *Gigaspora albida* completely failed to associate with bananas and growth was not less. AMF species indigenous to banana plantations performed just as well as exotic AMF species in enhancing growth of the tissue culture Giant Cavendish. There is high potential for the under-explored indigenous AMF species to enhance survival and subsequent establishment of tissue culture bananas.

Work in progress

Conservation agriculture for soybean production.

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Introduction

In 2006, during a problem identification exercise, farmers complained about the unpredictability of the rainfall. This led to the establishment of two pilot experiments on conservation agriculture. Conservation agriculture is based on three factors, which are believed to be needed simultaneously to guarantee success: crop rotation, crop residue to be kept, and zero tillage. Past research in Mexico (CIMMYT) showed the achievement of high and stable yields under conservation agriculture. Farmers in Opasi were very curious about this system, wherefore a pilot trial was setup.

Material and Methods

The first pilot experiment was setup to look at alternatives to chemical herbicide. This small trial was setup in the long rains of 2007 and is now in its second season. The field is located in Mukuyu, having a plot size of 2m * 3m, with only one replicate per treatment. All plots are soybean-maize rotation, 5 in maize stage (H513, 0,75 * 0,25m) and 5 in soybean stage (Namsoy, 0,25*0,05m). Treatments are: 1) normal ploughing + weeding / 2) normal ploughing + hand picking weeds / 3) land preparation cutting weeds by machete + hand picking weeds / 4) land preparation using a rake + hand picking weeds / 5) land preparation + weeding by hand picking. No yield data are yet available for this experiment, but labour and cost were recorded throughout both seasons.

The second pilot experiment was setup to follow the conventional conservation agriculture experimental setup: all three factors are tested in all combinations of with and without, in split-plot design. Three blocks of replicates were installed on one farmers' land in Opasi village. Plot size is 8x8m, IR-maize planted at 0,75m * 0,25m with 100kg DAP and 100kg urea per hectare, and soybean SB20 at 0,25m * 0,05m with 100kg DAP per hectare. The pre-emergence herbicide roundup max was used on the day of planting. The first season of the experiment was during the short rains of 2007. Therefore, no yields are yet available but field days were held with the farmers to vote for the best treatments and to make a budget analysis. Soil analysis was done at plot level and a soil pit was made for identification of the soil type in the different blocks.

Both experiments are farmer managed with researcher supervision. Farmers volunteered to provide land and labour but asked the researchers to supervise carefully to reach exact results.

Preliminary results

During a field day, a budget forecast was made with the farmers to estimate the cost and labour needed for each treatment **(Figure 26)**. Those data will be later compared with the real labour and cost data recorded in the monitoring books throughout the season. The forecast indicated the purchase of herbicide to be cheaper than the rent of oxen for ploughing, making no-tillage interesting. The non-labour cost of maize production was also higher than soybeans, as maize receives additional urea. The labour estimation was higher for no-tillage treatments than for tillage, as weeding becomes a problem in no-tillage systems. Farmers' votes were different for young and elder men **(Figure 26)**. No women attended the exercise.

Being the first season of the experiment, there is no rotation effect yet. Therefore, farmers voted for the best option for soybeans and the best option for maize. Young and elder all opted for keeping residues on the ground, young preferring with normal tillage, elder with no-tillage.

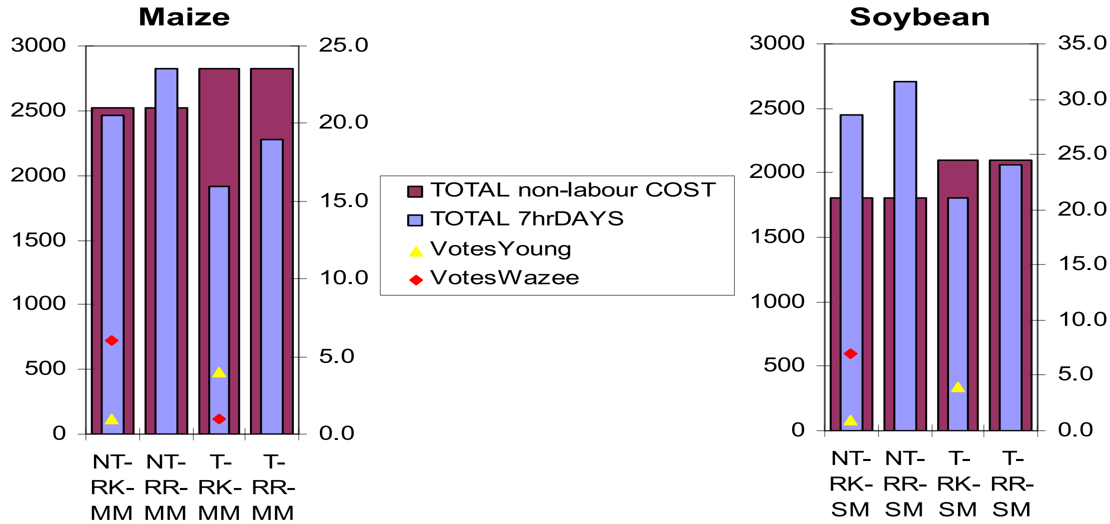

Figure 26: Budget forecast (COST in Kenyan Shilling and LABOUR in total days of 7 hours) for the different treatments, for maize and soybean, made by the farmers during the field days and the farmer's votes (young vs. elder (Wazee)). NT = No tillage / T = Tillage // RK = Residue Kept / RR = Residue Removed // MM = only maize, no rotation / SM = Soybean – Maize rotation.

Preliminary conclusions

The first season of the conservation agriculture experiment is known to be problematic, as weeds are still a large challenge. This first season some of the seeds were also damaged by the herbicide. Farmers are very interested in this experiment and find it strange to plant in non-prepared soil. If solutions can be found for increasing the easiness of weeding many farmers will be interested in this technology as labour availability is little within the households and herbicides are cheaper than hired labour.

Determination of genetic coefficients of dual purpose soybean varieties and their agro-ecological potential.

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Introduction

Soybean cultivation by farmers in Kenya is incipient. It is important to understand the reasons behind the lack of uptake of soybean in Kenya and identify the measures that are required to reverse this trend. Scaling up of soybean will require data on the performance of the different varieties under different agro-environments. Agronomic studies are therefore necessary to establish how different dual purpose varieties perform in Kenya under different conditions. However to do this, the genetic coefficients of these dual purpose varieties need to be determined.

Genetic coefficients are cultivar specific traits that determine daily growth and development as the plant responds to weather, soil characteristics, and management practices. Phenotypic characteristics (plant height, biomass, time to flowering, yield and others) and are a function of the environment and genetics. They will be used as a measure that depicts the genetic makeup and it is against these that genetic coefficients will be derived from. Trials were conducted in different sites in Kenya in 2006 and 2007. Seven improved dual purpose varieties (SB 20, SB 19, SB 17, SB 15, SB 9, SB 8 and SB 3) and one local variety (Nyala) were tested. The aim of the trials was to collect phenological and yield data that would be used to calibrate and validate the Decision Support System for Agro-technology Transfer (DSSAT) model. These genetic coefficients will then be used to simulate performance of these varieties for other areas in Kenya with known environmental conditions.

Materials and methods

The coefficients provided in the DSSAT model for various maturity groups were to provide the starting point in the process of determining the genetic coefficients:

- **EM-FL** Time - plant emergence and flower appearance (R1) (photothermal days)
- **FL-SH** Time - first flower and first pod (R3) (photothermal days)
- **FL-SD** Time - first flower and first seed (R5) (photothermal days)
- **SD-PM** Time - first seed (R5) and physiological maturity (R7) (photothermal days)
- **FL-LF** Time - first flower (R1) and end of leaf expansion (photothermal days)
- **SFDUR** Seed filling duration for pod cohort - (photothermal days)
- **SDPDV** Average seed per pod under standard growing conditions (#/pod)*
- **PODUR** Time required for cultivar to reach final pod load (photothermal days)
- **SLAVR** Specific leaf area of cultivar under standard growth conditions (cm2/g)
- **SIZLF** Maximum size of full leaf (three leaflets) (cm2)
- **WTPSD** Maximum weight per seed (g)

For the following we will use the standard DSSAT values.

- **LFMAX** Maximum leaf photosynthesis rate at 30 C, 350 vpm CO2, and high light
- **XFRT** Maximum fraction of daily growth that is partitioned to seed + shell

Performance trials can efficiently be used for extracting genetic coefficients using crop model (DSSAT) in an optimization mode. Different combinations of genetic coefficients are tested and the results compared with the measured data. The combination that gives the least mean square error will then be adopted for the various varieties.

Preliminary results

Nyala and SB 19 have the lowest SLA and LLA **(Table 15)**. This probably means that they have very narrow leaves, however, SB 19 records a high biomass with Nyala generally recording lowest among the varieties. This may be partly explained by the fact that SB 19 has a large number of leaves and it grows taller than Nyala. This is also evidenced by the fact that Nyala yields higher grain weight than SB 19 in the soybean productive areas (2006 data)

Table 15: Specific Leaf area Index and maximum Leaf Area (2007 data)

	Kakamega		Kitale		Msabaha		Njoro		Overall	
Variety	Mean SLA	Mean LLA	Mean SLA	Mean LLA	Mean SLA	Mean LLA	Mean SLA	Mean LLA	SLA	LLA
NYALA	125	122	145	147	127	88	155	80	138	109
SB15	216	266	213	328	162	188	232	180	206	240
SB17	217	284	214	273	170	122	224	267	206	236
SB19	150	136	169	85	160	79	94	91	143	98
SB20	216	175	216	203	177	101	254	113	216	148
SB3	153	215	195	248	168	125	229	168	186	189
SB8	219	217	220	238	178	161	226	128	211	186
SB9	247	134	270	153	173	120	240	153	233	140

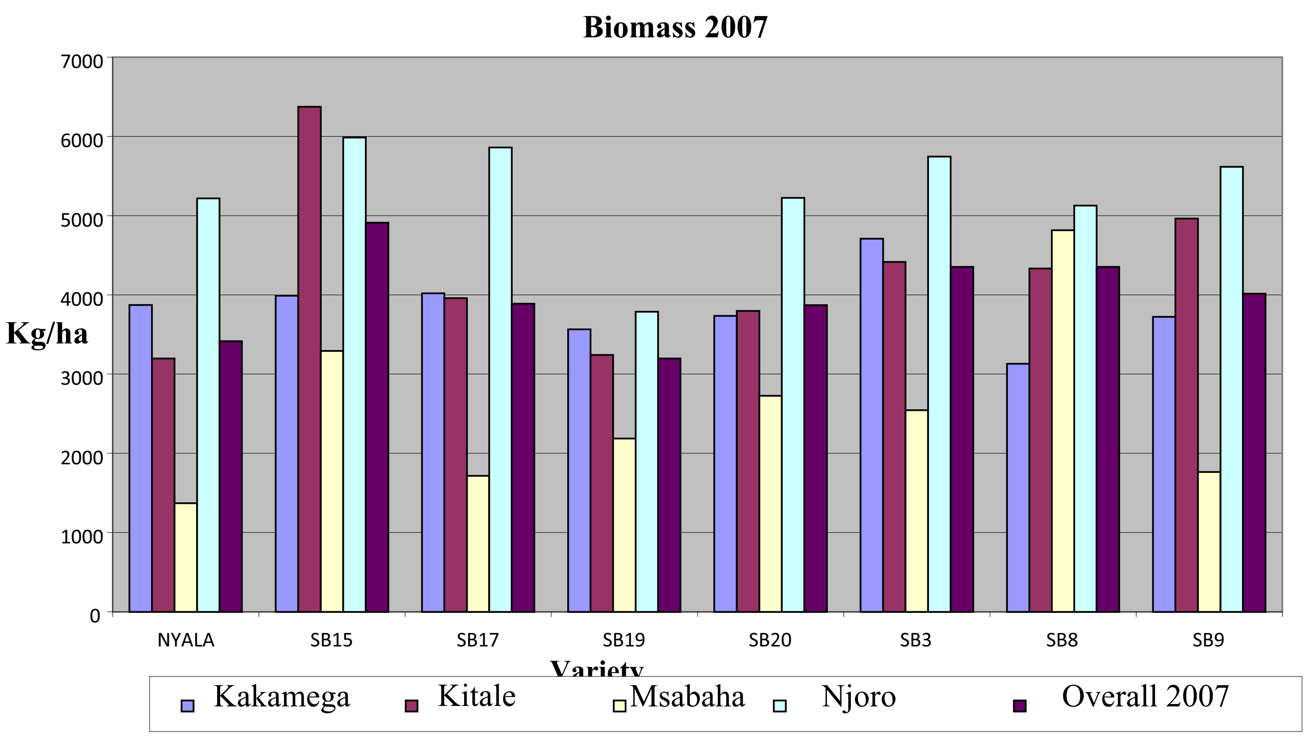

Figure 27: Biomass (2007 data)

Preliminary conclusions

Data from the four sites will be used in modeling to calibrate the DSSAT model. Genetic coefficients assigned to each variety will be used to predict/simulate production in other sites. At the moment we do not have a complete data set ready to get into the modeling proper phase.

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 Rwanda and DR Congo 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 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.

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.