# Output 1

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

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### Rationale

Sustainable agriculture is viewed here from a systems perspective in which the agroecosystem interacts with the atmospheric system and the hydrological cycle as well as with the social and economic systems of the community where it is practiced. This conceptual model transcends the classical boundaries of the biophysical sciences and requires integration with economics, sociology, anthropology and political science. In this context, output 1 deals with developing a mechanistic understanding of the physical, chemical and biological processes regulating soil fertility as a result of intensification and diversification of cropping systems and the recuperation of degraded lands. Nutrient cycling and organic matter dynamics are undoubtedly key drivers of agroecosystem function. There is increasing need, however, to address the issue of scale-dependence of different soil processes ranging from processes at the plant's rhizosphere, to nutrient gradients within farms or greenhouse gas emissions at the landscape scale.

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

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

**Key research questions:**

1. Can temporal and spatial heterogeneity at the farm, community, and landscape scale levels be exploited with sustainable land management (SLM) technologies that enhance production and/or improve ecosystem services?
2. How does loss of below-ground biodiversity (BGBD) relate to increasing land use intensity and what are the effects on ecosystem function?
3. To what extent is conservation agriculture applicable to different farming systems?

4. How can we build increased capacity for ISFM by integrating local and technical knowledge?
5. What are the socio-cultural and economic conditions, policies and institutions that influence ISFM?

## Output target 2008

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

**Published work**

**Tittonell[1,2], P., Zingore[3], S.M., van Wijk[1], T., Corbeels[3], M., Giller[1], K.E. (2007) Nutrient use efficiencies and crop responses to N, P and manure applications in Zimbabwean soils: Exploring management strategies across soil fertility gradients. Field Crops Research 100: 348-368**

*[1]Wageningen University, the Netherlands, [2]CIAT-TSBF, Kenya; [3]CIAT-TSBF, Zimbabwe*

**Abstract:** The spatial variability in crop yields commonly observed in smallholder farms of sub-saharan Africa is often caused by gradients of declining soil fertility with increasing distance from homestead. This heterogeneity means that recommendations based on regional soil surveys are of limited value. The variability in soil qualities within farms must be considered when designing management strategies, and their feasibility analyzed by integrating results at the farm livelihood scale. For this purpose, we have developed the model FARMSIM, a dynamic bio – economic model for analysis and exploration of trade – offs in resource and labour allocation in heterogeneous smallholder farms. Focusing on farm – scale strategies, the approach to stimulation of soil and crop processes in FARMISM (the sub – model FIELD) is designed to be simple, but to keep the necessary degree of complexity to capture heterogeneity in resource in resource use efficiencies. To test our approach, the sub-model FIELD was calibrated against chronosequences of woodland clearance in three agroecological zones of Zimbabwe (with soil textures of 3, 10, 35% clay), and used to stimulate: (i) the creation of soil fertility gradients, and (ii) different strategies of N, P and manure application to maize and soyabean rotations in homefields and outfields of smallholder farms on clayey and sandy soils. The results of simulation of management strategies were tested against on-farm experimental data from Murewa, Zimbabwe. The model produced satisfactory predictions ($r^2$: 0.6-0.9) of long – term changes in soil organic C, pf crop responses to N and P and of nutrient use efficiencies across a wide range of yields and different field types. This demonstration the broad applicability of the model despite the sparse data required for initialization. However, the model results were less accurate in predicting crop responses to N and P applications in the outfields on sandy soils. Experimental evidence indicated yield limitation by Ca and Zn deficiencies in highly depleted outfields on sandy soils, which were not included mechanistically in the current version of FIELD. Repeated applications of 16 t ha $^{-1}$ year $^{-1}$ of manure allowed larger responses to applied N and P after 3 years of experimentation; such a corrective effect of manure was simulated to be due to improved N and P recovery efficiencies in the model. In combination with the experimental data, the simulation results suggested that soil fertility gradients affect nutrient use efficiencies, operating mostly on the efficiencies of nutrient capture rather than conversion. A topology of fields according to the type of management interventions needed is introduced, based on a generic application of FIELD with this parameterization.

### Masvaya[1], E.N., Nyawasha[1], R.W., Zingore[2], S., Nyamangara[1], J., Delve[2], R.J. and Giller[3] K.E. (2007) Effect of farmer management strategies on spatial variability of soil fertility, crop nutrient uptake and maize fertilizer requirement in contrasting agro – ecological zones in Zimbabwe

*[1]University of Zimbabwe, Harare, [2]CIAT-TSBF, Zimbabwe; [3]Wageningen University, the Netherlands;*

**Abstract:** Soil fertility variability within and across farms poses a major challenge for increasing crop productivity in smallholder farming systems. A study was carried out to assess the effect of farmers' resource management strategies on soil fertility variability and plant nutrient uptake on smallholder farms in Gokwe South (~650 mm yr$^{-1}$) and Murewa (~850 mm yr$^{-1}$) Districts of Zimbabwe. Farmers were grouped into: resource-endowed (RG 1), intermediate (RG 2) and resource-constrained (RG 3). In Murewa, wealthy farmers applied large amounts of manure (>10 t ha$^{-1}$ yr$^{-1}$) on fields closest to homesteads (homefields) and none to fields further away (outfields) and this created gradients of decreasing soil fertility with increasing distance from the homesteads. Soil available P most concentrated on homefields (8-13 mg kg$^{-1}$) of wealthy farms and to 2-6 mg kg$^{-1}$ on outfields and all fields on poor farms. At both sites, maize grain yields in farmers' fields were largest on the homefields on the wealthy farms (2.7–5.0 t ha$^{-1}$), but poor across all fields on the poor farms (0.3–1.9 t ha$^{-1}$). Maize responded significantly to addition of N and P on homefields in Murewa and all fields in Gokwe, but responded poorly on degraded outfields in Murewa due to deficiencies Ca and Zn. Consideration of key factors driving soil fertility variability including soil type, farmer management practices and agro-ecology is required when developing fertilizer recommendations.

### Pypers[1], P., Huybrighs[2], M., Diels[1], J., Abaidoo[3], R., Smolders[2], E. and Merckx[2], R. (2007) Does the enhanced P acquisition by maize following legumes in a rotation result from improved soil P availability? Soil Biology & Biochemistry 39: 2555-2566.

*[1]CIAT-TSBF, Kenya; [2]K.U.Leuven, Belgium;[3]IITA, Nigeria*

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

However, the rotation effect was unrelated to internal P concentration: significantly larger yields were obtained for maize following velvet bean than for maize following maize at identical internal P. This suggested the presence of another growth-limiting, possibly soil biological factor which is counteracted by the previous velvet bean growth. In conclusion, our results confirmed that the introduction of a legume supplied with PR into a maize-based cropping system increases yield and P-uptake by a subsequent maize crop, compared to maize following a first maize crop supplied with PR. These stimulations were, however, unrelated to improved P nutrition. Results strongly suggested that the legume in the rotation system has other positive, possibly soil – microbiological effects which enhance maize growth and production

### Andre´n[1], O., Kihara[2], J., Bationo[2], A., Vanlauwe[2], B. and Katterer[1] T. (2007) Soil Climate and Decomposer Activity in Sub-Saharan Africa Estimated from Standard Weather Station Data: A Simple Climate Index for Soil Carbon Balance Calculations. Ambio Vol. 36, No. 5, July 2007

*[1]SLU, Sweden; [2]CIAT-TSBF, Kenya*

**Abstract:** Soil biological activity was calculated on a daily basis, using standard meteorological data from African weather stations, a simple soil water model, and commonly used assumptions regarding the relations between temperature, soil water content, and biological activity. The activity factor re_clim is calculated from daily soil moisture and temperature, thereby taking the daily interaction between temperature and moisture into account. Annual mean re_clim was normalized to 1 in Central Sweden (clay loam soil, no crop), where the original calibration took place. Since soils vary in water storage capacity and plant cover will affect transpiration, we used this soil under no crop for all sites, thereby only including climate differences. The Swedish re_clim value, 1, corresponds to ca. 50% annual mass loss of, e.g., cereal straw incorporated into the topsoil. African mean annual re_clim values varied between 1.1 at a hot and dry site (Faya, Chad) and 4.7 at a warm and moist site (Brazzaville, Congo). Sites in Kenya ranged between re_clim ¼ 2.1 at high altitude (Matanya) and 4.1 in western Kenya (Ahero). This means that 4.1 times the Swedish C input to soil is necessary to maintain Swedish soil carbon levels in Ahero, if soil type and management are equal. Diagrams showing daily re_clim dynamics are presented for all sites, and differences in within-year dynamics are discussed. A model experiment indicated that a Swedish soil in balance with respect to soil carbon would lose 41% of its soil carbon during 30 y, if moved to Ahero, Kenya. If the soil was in balance in Ahero with respect to soil carbon, and then moved to Sweden, soil carbon mass would increase by 64% in 30 y. The validity of the methodology and results is discussed, and re_clim is compared with other climate indices. A simple method to produce a rough estimate of re_clim is suggested.

### Waswa[1,2], B.N., Mugendi[1], D.N., Vanlauwe[2], B. and Kung'u[1], J. (2007) Changes in Soil Organic Matter as Influenced by Organic Residue Management Regimes in Selected Experiments in Kenya. In: A. Bationo (eds.), Advances in Integrated Soil Fertility Research in Sub-Saharan Africa: Challenges and Opportunities, 457–469 Springer.

*[1]Environmental Studies, Kenyatta University, Kenya; [2]CIAT-TSBF, Kenya*

**Abstract:** The failure to understand the dynamics of soil organic matter (SOM) is a major limitation to the sustainability of smallholder production that predominantly relies on organic resources for the maintenance of soil fertility. This study evaluated the influence of organic resource management on SOM in three selected experiments in central and

western highlands of Kenya. Soil carbon (C), nitrogen (N) and carbon-13 ($^{13}C$) values in the three experiments were varied depending on the amounts of the organic residues applied as well as the duration of application indicating that organic residue management practices have a profound impact on the final contribution to the SOM pools. Kabete experiment had the narrowest C, N and $^{13}C$ values pointing to its young age as well as the low quantity of the organic residues applied. On the other hand, Embu experiment had soil C values above the critical level of 2.0% indicating a positive effect of continued application of organic residues. In all the three sites, aggregate mineral fraction (MF) size distribution were dominated by macroaggregates (250–500 µm and >500 µm) which on average accounted for about 72%, 65% and 69% of the dry soil weight for Maseno, Kabete and Embu experiments, respectively. Similarly higher proportions of aggregate light fractions (LF) C and N were observed in macroaggregate fractions for the three experiments with organic treatments having higher proportions. The $^{13}C$ signatures of the LF in the macroaggregates (>250 µm) were more negative as compared to the $^{13}C$ values in the microaggregate (53–250 µm) LF suggesting a more C contribution from C3 vegetation to the most recently incorporated SOM pool

**Baaru[1], M.W., Mungendi[1], D.N., Bationo[2], A., Verchot[3], L., Waceke[1], W. (2007) Soil microbial biomass carbon and nitrogen as influenced by organic and inorganic inputs at Kabete, Kenya. In: A. Bationo (eds.), Advances in Integrated Soil Fertility Research in Sub-Saharan Africa: Challenges and Opportunities, 827–832 Springer.**

*[1]Environmental Foundation, Kenyatta University, Kenya; [2]CIAT-TSBF, Kenya; [3]ICRAF, Kenya*

**Abstract:** Soil microbial biomass is the main driving force in the decomposition of organic materials and is frequently used as an early indicator of changes in soil properties resulting from soil management and environment stresses in agricultural ecosystems This study was designed to assess the effects of organic and inorganic inputs on soil microbial biomass carbon and nitrogen overtime at Kabete, Kenya. *Tithonia diversifolia*, *Cassia spectabilis, Calliandra calothyrsus* were applied as organic resources, and Urea as inorganic source. Soil was sampled at 0–10 cm depth before incorporating the inputs and every two months thereafter and at harvesting in a maize-cropping season. Soil microbial biomass carbon and nitrogen was determined by Fumigation Extraction method (FE) while carbon evolution was measured by Fumigation Incubation (FI) method. The results indicated a general increase in soil microbial biomass carbon and nitrogen in the season with the control recording lower values than all the treatments. Microbial biomass carbon, nitrogen and carbon dioxide evolution was affected by both quality of the inputs added and the time of plant growth. Tithonia recorded relatively higher values of microbial biomass carbon, nitrogen and carbon evolution than all the other treatments. A significant difference was recorded between the control and the organically treated soils at the season for the microbial biomass nitrogen and carbon dioxide evolution. Both the microbial biomass C and N showed a significance difference ($P \leq 0.05$) in the different months of the season

**Kimiti[1] J.M., Esilaba[2] A.O., Vanlauwe[3] B. and Bationo[3] A. (2007) Participatory Diagnosis in the Eastern Drylands of Kenya: Are Farmers aware of their Soil Fertility Status? In: A. Bationo (eds.), Advances in Integrated Soil Fertility Research in Sub-Saharan Africa: Challenges and Opportunities, 957–963 Springer.**

*[1]Kenya Forestry Research Institute, Kenya; [2]Kenya agricultural Research Institute, Kenya, [3]CIAT-TSBF, Kenya*

**Abstract:** A participatory diagnosis (PD) was carried out in Makueni District, eastern Kenya, with a view of identifying farmer awareness on soil fertility status so as to identify gaps for research on soil fertility improvement. The results indicate that farmers are aware of soil types, soil characteristics soil, soil fertility status and soil distribution of different soil types in their villages. In addition, the farmers are aware of declining soil fertility, which they attributed to soil erosion, continuous cropping, poor methods of cultivation, and inadequate farm inputs. The farmers use farmyard manure to improve soil fertility and are aware of the quality of different manures used in their farms. The types of farmyard manures as ranked by farmers in decreasing quality are poultry manure>goat manure>cattle manure. However it was revealed that cattle manure is commonly used because it is readily available though not adequate. Crop residues, especially those of grain legumes, are also used for soil fertility improvement. In this paper the results of farmer participation research meetings with emphasis on soil fertility management in eastern Kenya are discussed

**Abaidoo[1,2], R.C. Keyser[1], H.H. Singleton[1], K.E. Dashiell[2], P.W., and Sanginga[3], N. (2007) Population size, distribution, and symbiotic characteristics of indigenous Bradyrhizobium spp. that nodulate TGx soybean genotypes in Africa. Applied Soil Ecology 35:57-67**

*[1]University of Hawaii, United States; [2]IITA, UK; [3]CIAT-TSBF, Kenya*

**Abstract:** Soils of many potential soybean fields in Africa are characterized by low levels of biological nitrogen fixation(BNF) activities and often cannot support high soybean yields without addition of inorganic N fertilizers or external application of soybean rhizobia. Themostprobablenumber (MPN) technique was used to determine the bradyrhizobial populations that nodulate TGx soybean genotypes (across between nonpromiscuous North American soybean genotypes and promiscuous Asian soybean genotypes), cowpea or North American soybean cv. Clark IV, in soils from 65 sites in 9 African countries. The symbiotic effectiveness of isolates from these soils was compared to that of Bradyrhizobium japonicum strain USDA110. The bradyrhizobial population sizes ranged from 0to$10^4$ cellsg$^{-1}$ soil. Bradyrhizobium sp. (TGx) populations were detected in 72% and B. japonicum (Clark) in 37% of the soil samples. Bradyrhizobium sp. (TGx) populations were generally low, and significantly less than that of the cowpea bradyrhizobial populations in 57% of the samples. Population sizes of less than 10cellsg$^{-1}$ soil were common as these were detected in at least 43% of the soil samples. B. japonicum (Clark) occurred in higher population densities in research sites compared to farmers' fields. Bradyrhizobium sp. (TGx) populations were highly correlated with biotic but not abiotic factors. The frequent incidence of low Bradyrhizobium sp. (TGx) populations is unlikely to support optimum BNF enough for high soybean yields while the presence of B. japonicum (Clark) in research fields has the potential to compromise the selection pressure anticipated from the indigenous Bradyrhizobium spp. (Vigna) populations. Bradyrhizobium isolates could be placed in four symbiotic phenotype groups based on their effectiveness on a TGx soybean genotype and the North American cultivar Clark IV. Symbiotic phenotype group II isolates were as effective as B. japonicum strain USDA110 on both soybean genotypes while isolates of group IV were effective on the TGx soybean genotype but not on the Clark IV. The group IV isolates represent a unique sub group of indigenous bradyrhizobia that can sustain high soybean yields when available insufficient population densities.

**Kathuku[1], A.N., Kimani[1], S.K., Okalebo[2], J.R., Othieno[2], C.O. and Vanlauwe[3], B. Integrated Soil Fertility Management: Use of NUTMON to Quantify Nutrient Flows in Farming Systems in Central 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 283-288.**

*[1]KARI, Kenya; [2] Moi University, Kenya; [3]CIAT-TSBF, Kenya*

**Abstract:** A study based on Participatory Learning and Action Research (PLAR) to categorize soil fertility management was carried out in three districts of Central Kenya: Kirinyaga, Maragua and Kiambu. The PLAR classified farms according to their economic and soil fertility management status. In each district 20–30 farmers were selected who represented three hundred farmers. The selected farmers had discussions with the facilitators who grouped them into three categories according to their soil fertility management level: Good (Class I), Average (Class II) and poor (Class III). Three farmers in Classes I and II and four in Class III were selected to represent the groups. Out of the selected representatives in each group, two were selected for Nutrient Monitoring (NUTMON) questionnaire assessment and this was done during the short rains cropping season. The farmers were visited at their homes and researchers had free discussions with them related to their farming systems and soil fertility management. Farm plans were drawn, fertilizer and manure inputs recorded and cash in and out flows monitored. Results were analyzed using NUTMON software model. Results showed a general trend of negative nutrient balances particularly in food crop fields. Mineral nutrient inputs (IN1) was high in classes II and I but low in class III, low negative nutrient balances were recorded in Kiambu district while Maragua district had higher nutrient balances. In fields where both organic and inorganic nutrient sources were used had positive nutrient balances.

## Work in progress

### Nutrient deficiency and unavailability in the soils of Walungu, South-Kivu, Democratic Republic of Congo

**E. Vandamme[1], P. Pypers[2], B. Vanlauwe[2]**

*[1]Catholic University of Leuven, Belgium; [2]CIAT-TSBF, Kenya*

The soils in the area of Walungu of Eastern DR Congo are unproductive and serious yield losses are common due to high population pressure and low use of fertilizer and animal manure. A pot trial was set up at the INERA research center in Mulungu to identify the major limiting nutrients, using a representative range of soils.

Two groups of soils were used. First, 15 soils were sampled from sites with on-going legume evaluation and multiplication activities (‘Project soils’). Secondly, 15 randomly chosen additional soils were sampled, coming from sites randomly selected during the farm-level characterisation of the area (‘Final Characterization soils’). These two groups of soils were selected in order to investigate whether nutrient limitations would be different between sites selected for activities and completely randomly selected soils. Six treatments were imposed: control (no inputs), ‘All’ (all nutrients added: N, P, K, Mg, S, Ca, Zn, Fe, B, Cu, Mn and Mo), ‘All-P’, ‘All-N’, and ‘All-K’. The pots were filled with 2, 5 kg of soil, after which the soil of each pot was mixed with nutrient solutions according to the different treatments. The pots were then organized in a randomized complete block design with 3 replicates. In each pot 3 seeds of maize were sown, using the maize variety Katumani, and thinned after one week. Moisture conditions were kept optimal in the course of the trial. Regularly, the height of the growing plants was measured. At 5 weeks after sowing, plants were harvested and sun-dried in closed paper bags. After sun-drying, plants were oven-dried and weighted and stored for further analysis.

Clear treatment differences became visible in course of the experiment **(Figure 2).** At 32 days after planting, heights for the treatments ‘Control’ and ‘All – P’ were as low as 50cm compared to heights until 85cm for the ‘All’ treatment. Plant heights showed no significant difference between the ‘Control’ and the ‘All – P’ treatment. Further, response to other nutrients then P were differential, but in general no clear differences could be found between ‘All’, ‘All – K’ and ‘All – N’ treatments, and this for both groups. No clear differences were found between both groups of soils.

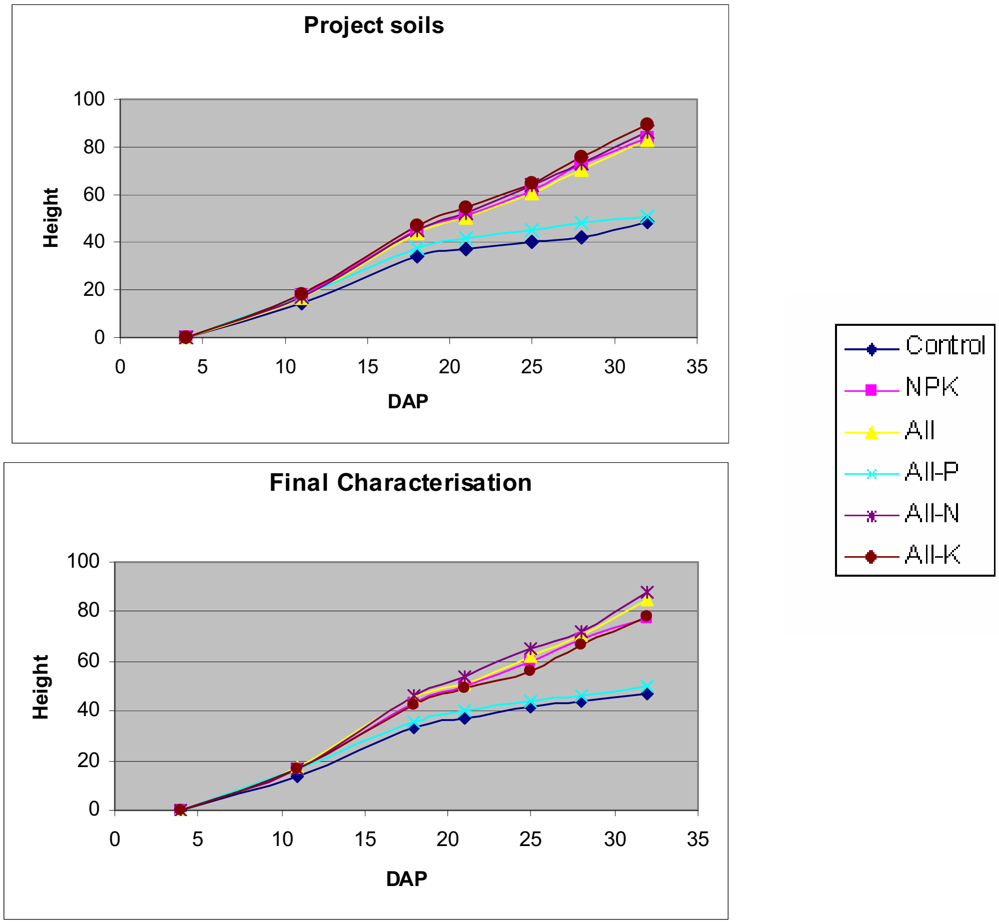

**Figure 2:** Height of maize plants for the ‘Project soils’ and the ‘Final Characterisation soils’.

The results prove that P is a primary limiting factor of crop growth in the region. The general character of the phosphate problem in the region is further demonstrated by the fact that no clear differences were found between both groups of soils. Other nutrients did not appear to be limiting but obviously, field tests are required to confirm this.

## Output target 2008

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

**Published work**

**Tittonell[*], P., Shepherd[2], K., Vanlauwe[1], B., and Giller[3], K.E. (2007) Unraveling the effects of soil and crop management on maize productivity in smallholder agricultural systems of western Kenya – an Application of classification and regression tree analysis Agriculture, Ecosystems, and Environment 123, 2007, 137-150.**

*[1]CIAT-TSBF, Kenya; [2]ICRAF, Kenya; [3]WUR, the Netherlands*

**Abstract:** To guide soil fertility investment programmes in sub-Saharan Africa, better understanding is needed of the relative importance of soil and crop management factors in determining smallholder crop yields and yield variability. Spatial variability in crop yields within farms is strongly influenced by variation in both current crop management (e.g. planting dates, fertilizer rates) and soil fertility. Variability in soil fertility is in turn strongly influenced by farmers' past soil and crop management. The aim of this study was to investigate the relative importance of soil fertility and crop management factors in determining yield variability and the gap between farmers' maize yields and potential yields in western Kenya. Soil fertility status was assessed on 522 farmers' fields on 60 farms and paired with data on maize-yield and agronomic management for a sub-sample 159 fields. Soil samples were analyzed by wet chemistry methods (1/3 of the samples) and also by near infrared diffuse reflectance spectroscopy (all samples). Spectral prediction models for different soil indicators were developed to estimate soil properties for the 2/3 of the samples not analyzed by wet chemistry. Because of the complexity of the data set, classification and regression trees (CART) were used to relate crop yields to soil and management factors. Maize grain yields for fields of different soil fertility status as classified by farmers were: poor, 0.5–1.1; medium, 1.0–1.8; high, 1.4–2.5 t ha_1. The CART analysis showed resource use intensity, planting date, and time of planting were the principal variables determining yield, but at low resource intensity, total soil N and soil Olsen P became important yield-determining factors. Only a small group of plots with high average grain yields (2.5 t ha_1; n = 8) was associated with use of nutrient inputs and good plant stands, whereas the largest group with low average yields (1.2 t ha_1; n = 90) was associated with soil Olsen P values of less than 4 mg kg_1. This classification could be useful as a basis for targeting agronomic advice and inputs to farmers. The results suggest that soil fertility variability patterns on smallholder farms are reinforced by farmers investing more resources on already fertile fields than on infertile fields. CART proved a useful tool for simplifying analysis and providing robust models linking yield to heterogeneous crop management and soil variables.

**Tittonell[*], P., Vanlauwe[1], B., de Ridder[2], N. and Giller[2], K.E. (2007) Heterogeneity of crop productivity and resource use efficiency within smallholder African farms: soil fertility gradients or management intensity gradients? Agricultural Systems 94, 2007, 376-390.**

*[1]CIAT-TSBF, Kenya; [2]WUR, Netherlands*

**Abstract:** The decrease in crop yields at increasing distances from the homesteads within smallholder farms of Sub-Saharan Africa (SSA) is normally ascribed to the existence of within-farm soil fertility gradients. Field observations also suggest that a large part of such variability is concomitantly caused by poor agronomy. To understand the interaction between soil fertility (S factors) and management decisions (M factors) affecting crop variability, we combined field research conducted in western Kenya (Vihiga, Kakamega and Teso districts; rainfall: 1600, 1800 and 1200 mm, respectively) with explorations using the simple dynamic crop/soil model for dynamic simulation of nutrient balances, previously tested for the region. Field measurements indicated within-farm differences in average maize grain yields of 48% (2.7 vs. 1.4 t ha_1) in Vihiga and of 60% (1.5 vs. 0.6 t ha_1) in Teso, between fields that were close and far from the homestead, respectively. Extreme values ranged widely, e.g. between 4.9 and 0.3 t ha_1 for all the farms surveyed in Vihiga, where the average farm size was 0.6 ha. Maize grain yields tended to increase with increasing contents of soil C, total N, extractable P and exchangeable bases. However, the negative relationship between S factors and distance from the homestead was not as strong as expected, and yield variability was better explained by multiple regression models considering M factors such as planting date, plant density, resource use and weed infestation (40–60% across sites). Then, we analyzed the variation in resource (cash, labour, N) use efficiency within farms of different resource endowments with the aid of the simulation model. N balances at plot scale varied from ca. +20 to _18 kg ha_1, from _9 to _20 kg ha_1 and from _16 to _18 kg ha_1 for the different fields of the high, medium and low resource endowment case-study farms, respectively. Labour productivities ranged between ca. 10 and 38 kg grain man-day_1 across field and farm types. The results indicate the need of considering within farm heterogeneity when designing soil fertility management interventions.

Resource use efficiency was strongly affected by soil quality. As farmers invest more effort and resources in the more productive and less risky fields, the interaction between S and M factors leads to farmer-driven resource use efficiency gradients within smallholder farms.

**Kimiti[1], J.M, Esilaba[2], A.O., Vanlauwe[3], B. and Bationo[3], A. (2007) Participatory Diagnosis in the Eastern Drylands of Kenya: Are Farmers aware of their Soil Fertility Status? 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, 957-964**

*[1]KEFRI, Kenya; [2]KARI, Kenya; [3]CIAT-TSBF, Kenya*

**Abstract:** A participatory diagnosis (PD) was carried out in Makueni District, eastern Kenya, with a view of identifying farmer awareness on soil fertility status so as to identify gaps for research on soil fertility improvement. The results indicate that farmers are aware of soil types, soil characteristics soil, soil fertility status and soil distribution of different soil types in their villages. In addition, the farmers are aware of declining soil fertility, which they attributed to soil erosion, continuous cropping, poor methods of cultivation, and inadequate farm inputs. The farmers use farmyard manure to improve soil fertility and are aware of the quality of different manures used in their farms. The types of farmyard manures as ranked by farmers in decreasing quality are poultry manure>goat manure>cattle manure. However it was revealed that cattle manure is commonly used because it is readily available though not adequate. Crop residues, especially those of grain legumes, are also used for soil fertility improvement. In this paper the results of farmer participation research meetings with emphasis on soil fertility management in eastern Kenya are discussed

## Work in progress

### Development Domains for the Conservation Agriculture (CA) Austria Project in Central Mozambique

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The CA Austria project is being implemented in two strategic transects across Manica and Sofala Provinces of central Mozambique and aims to evaluate promising interventions for reducing the production vulnerability of smallholder farmers in central Mozambique through the improved use of germplasm, nutrients and water. The project is testing and disseminating improved agricultural production systems based on drought and disease tolerant germplasm and improved natural resource use based on conservation agriculture (CA) principles, through participatory on-farm experimentation by farmers, combined with spatial analysis tools to characterize problems and help target interventions. It is evaluating the trade-offs of adopting interventions and addressing critical development questions.

A component of the research methodology and procedure is defining farmer recommendation domains based on land use, agro climatic conditions, risk analysis and other criteria, aided by spatial analysis. These recommendation domains are to be hypothesized after the first season's data and will continue to be updated during the course of the project.

This Report details how the initial recommendation domains were developed using the following variables: - Market Access, Rainfall and Elevation. The criteria for the domains will be further developed when top soils and risk analysis data are available. These will be incorporated in the recommendation domains for the extrapolation/scaling out of tested farmer-approved component technologies.

Market access is critical for determining the comparative advantage of any given location given its potential agricultural productivity. The methodology for Market access modeling was based upon the Accessibility Modeling tool for ArcView 3 extension (Farrow et al 2001). The Arc View tool takes into account the effects of land use classes and slope on travel times. The slope grids used were derived from the 90m SRTM digital elevation model DEM.

Rainfall is one of the important agro- climatic conditions that determine the agricultural potential of any location.

The rainfall data used was obtained from the World
Climate database (Hijmans et al, 2005) which is available at a resolution of 1km2. This data are interpolated and are based on 48 000 rainfall stations worldwide with a good coverage for eastern and southern Africa. The WorldClim database gives monthly mean values for rainfall and temperature but there are no data on the year to year variability of annual rainfall totals.

## Elevation

Elevation is the factor used in defining the initial development domains for the CA Austria project. The altitude data was obtained from the SRTM digital elevation model (DEM).

## Development domain production

Using raster analysis the three input variables (market access, elevation and rainfall) were overlaid to form a set of development domains for the CA Austria project. The three variables used to define the development domains were classified as high, medium and low and the thresholds used for the analysis are shown in **(Table 1)** below.

**Table 1:** Thresholds used to classify the variables

| Variable | Low | Medium | High |
|---|---|---|---|
| Market Access | 3 – 100hrs | 1 – 3 hrs | 0 – 1 hr |
| Elevation | < 500(masl) | 500 – 1 000(masl) | > 1 000(masl) |
| Rainfall | < 900mm | 900 – 1 300mm | > 1300mm |

## Results

Of the 27 possible development domains, only 8 are encountered in the demonstration sites **(Figure 3)**. The dominant domain in terms of area is the region that has medium access to markets, low elevation and experiences rainfall in excess of 1300mm per annum. The sites found in this domain are: Dovenhe in Chibavababava, Inhadijou and Puanda in Buzi. The least of the domains in terms of area is Nzeme in Angonia with high market access, high elevation and receives medium rainfall. **(Table 2)** below shows the area statistics for the 27 possible development domains.

**Table 2:** Area statistics of the development domains.

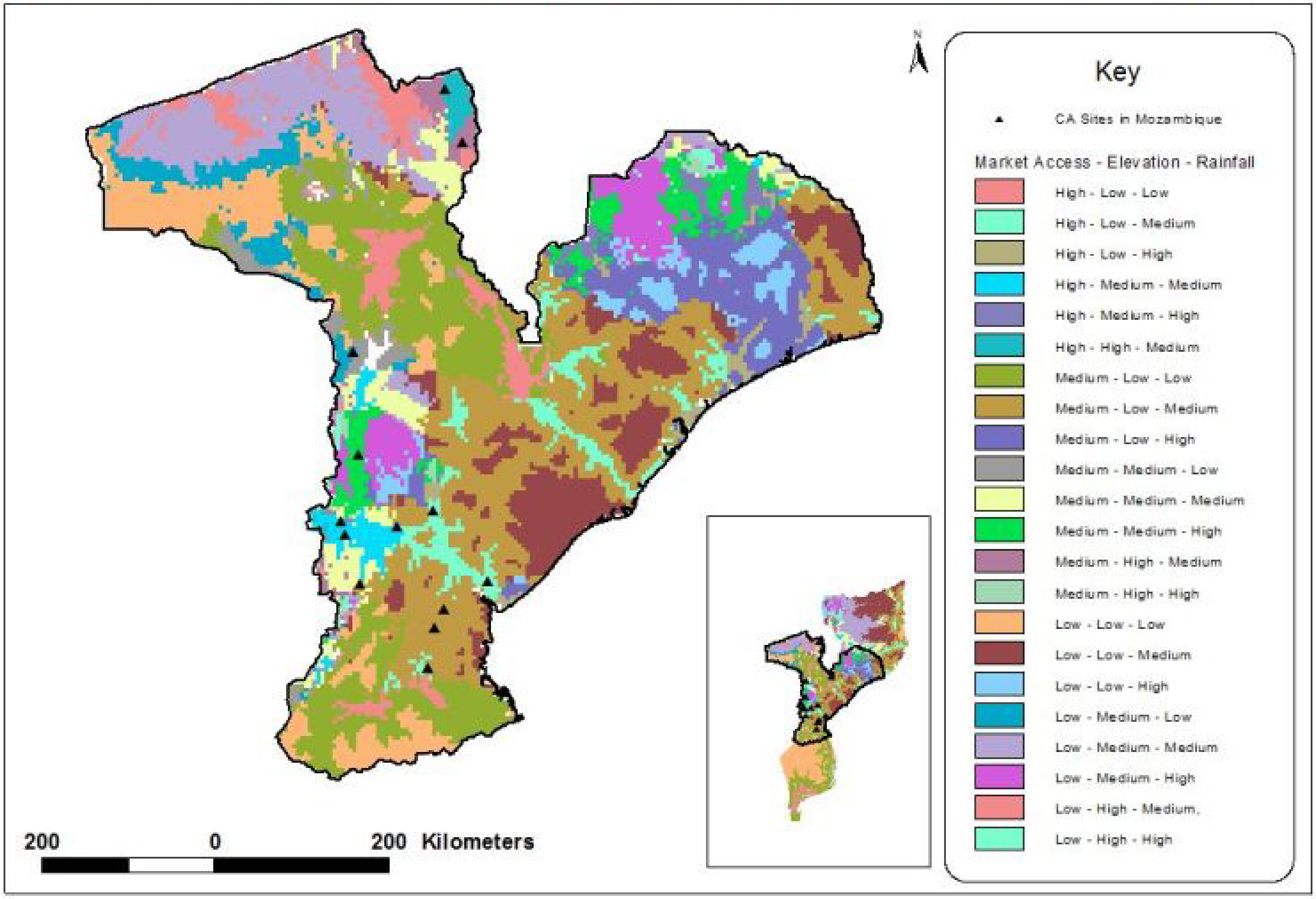
| **Domain**<br>**Market Access- Elevation- Rainfall** | **Land Area (km$^2$)** | **% of Total area** |
|---|---|---|
| High – Low – Low | 9238.4917 | 2.795752 |
| High – Low - Medium | 11880.6983 | 3.595336 |
| High – Low – High | 3698.7872 | 1.119327 |
| High – Medium - Low | 1037.1206 | 0.313853 |
| High – Medium - Medium | 4690.0351 | 1.419298 |
| High – Medium - High | 2980.0766 | 0.901831 |
| High – High – Low | 21.4999 | 0.006506 |
| High – High - Medium | 1983.6621 | 0.600296 |
| High – High - High | 36.2200 | 0.010961 |
| Medium – Low - Low | 49085.1108 | 14.85413 |
| Medium – Low - Medium | 63840.7309 | 19.31948 |
| Medium – Low - High | 22318.9685 | 6.754165 |
| Medium – Medium - Low | 5866.7954 | 1.775409 |
| Medium – Medium - Medium | 12272.7852 | 3.71399 |
| Medium – Medium - High | 12012.7793 | 3.635307 |
| Medium - High - Low | 21.4999 | 0.006506 |
| Medium – High - Medium | 3616.3162 | 1.094369 |
| Medium – High - High | 1606.8804 | 0.486274 |
| Low – Low – Low | 27038.4823 | 8.182384 |
| Low – Low - Medium | 29884.9182 | 9.043772 |
| Low – Low – High | 8576.6023 | 2.595451 |
| Low – Medium - Low | 10058.6671 | 3.043953 |
| Low – Medium -Medium | 26869.0723 | 8.131117 |
| Low – Medium - High | 12450.6519 | 3.767816 |
| Low – High – Low | 42.9998 | 0.013013 |
| Low – High - Medium | 8255.5172 | 2.498284 |
| Low – High – High | 1062.1154 | 0.321417 |

## Conclusions

The report presents the results of initial development domains developed for the CA Austria project using spatial analysis. The spatial analysis work will mostly contribute to Output 4 of the overall project in the extrapolation of improved crop water productivity technologies from plot and field level, to the watershed level. As more data for criteria development is collected the development domains are to be further developed.

**Figure 3:** Map showing the CA demonstration sites in Mozambique and domains for further site selection

## CA Demonstration Sites in Mozambique and Domains for further Site Selection



### Effect of farmer management strategies on spatial variability of soil fertility, crop nutrient uptake and maize fertilizer requirement in contrasting agro-ecological zones in Zimbabwe.

**E. Masvaya[1], J. Nyamangara[1], S. Zingore[2] R.J. Delve[2], and K.E. Giller[3],**

[1]*Universtiy of Zimbabwe;* [2]*CIAT-TSBF, Zimbabwe;* [3]*WUR The Netherlands*

Soil fertility variability within and across farms poses a major challenge for increasing crop productivity in smallholder farming systems. A study was carried out to assess the effect of farmers' resource management strategies on soil fertility variability and plant nutrient uptake on smallholder farms in Gokwe South (~650 mm $yr^{-1}$) and Murewa (~850 mm $yr^{-1}$) Districts of Zimbabwe. Farmers were grouped into: resource-endowed (RG 1), intermediate (RG 2) and resource-constrained (RG 3). In Murewa, wealthy farmers applied large amounts of manure (>10 t $ha^{-1}$ $yr^{-1}$) on fields closest to homesteads (homefields) and none to fields further away (outfields) and this created gradients of decreasing soil fertility with increasing distance from the homesteads. Soil available P most concentrated on homefields (8-13 mg $kg^{-1}$) of wealthy farms and to 2-6 mg $kg^{-1}$ on outfields and all fields on poor farms. At both sites, maize grain yields in farmers' fields were largest on the homefields on the wealthy farms (2.7–5.0 t $ha^{-1}$), but poor across all fields on the poor farms (0.3–1.9 t $ha^{-1}$). Maize responded significantly to addition of N and P on homefields in Murewa and all fields in Gokwe, but responded poorly on degraded outfields in Murewa due to deficiencies Ca and Zn. Consideration of key factors driving soil fertility variability including soil type, farmer management practices and agro-ecology is required when developing fertilizer recommendations.

### Determinants of Fertilizer Use in the Chinyanja Triangle of Malawi, Zambia and Mozambique.

**S. Zingore[1], R. Mageta[1], J. Njuki[3], M. Mapila[3], R.J. Delve[1],**

[1]*CIAT-TSBF, Zimbabwe;* [2]*CIAT-TSBF, Malawi*

To sustain food production systems in the SSA and to increase yields, there is the need for substantial increases in use of appropriate inorganic fertilizers as they offer the most effective means of increasing crop productivity (Wilchens, 2006; Weight *et al*, 1998) and they are a means to curtailing nutrient mining. The research challenge in the region has been to assess why the increased use of inorganic fertilizer has not been a precursor to economic growth. Under this challenge, an overarching research agenda has been to assess the social economic factors affecting the use of inorganic fertilizers at the household level. Using econometric analysis, studies have been on going in the Chinyanja Triangle of Malawi, Zambia and Mozambique to analyze the socioeconomic processes and factors that influence use of inorganic fertilizers within the maize based farming systems that are common in the area. The results of the regression model are presented in **(Table 3)** and discussed below and they show that despite similar geographical and cultural practices in the Chinyanja Triangle, different socioeconomic variables have different influences on the use of inorganic fertilizers.

**Table 3:** Factors Affecting Quantity of Fertilizer Applied per Acre for Malawi, Zambia and Mozambique in the 2006/07 season

| | **Malawi** | | | **Zambia** | | | **Mozambique** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Coefficient Estimates** | **t-values** | **Þ- Values** | **Coefficient Estimates** | **t-values** | **Þ- Values** | **Coefficient Estimates** | **t-values** | **Þ- Values** |
| Constant | 48.392 | 1.57 | | 137.086 | 1.39 | .168 | -45.846 | -1.22 | .263 |
| ***Household characteristics*** | | | | | | | | | |
| Sex of household head | -.134 | -1.57 | .119 | .104 | .824 | .413 | .145 | .690 | .513 |
| Women Consulted on fertilizer use | -.177 | -2.03 | .045* | -.134 | -.951 | .345 | -.810 | -3.19 | .015** |
| Residential status of head | .127 | 1.55 | .123 | - | - | - | -.189 | -.916 | .390 |
| Respondent has lived outside village | -.081 | -.910 | .365 | - | - | - | - | - | - |
| Savings | - | - | - | .264 | 1.97 | .053* | .757 | 4.27 | .004** |
| Total Income | - | - | - | .259 | 2.12 | .038* | .218 | 1.407 | .202 |
| Value of assets | -.136 | -1.47 | .145 | .258 | 1.71 | .093* | - | - | - |
| Marital Status | - | - | - | - | - | - | .440 | 2.37 | .050* |
| **Social and Human Capital Characteristics** | | | | | | | | | |
| Access to Extension | - | - | - | -.182 | -1.63 | .109 | - | - | - |
| Participation | .169 | 1.97 | .051 | .106 | .775 | .442 | .314 | 1.57 | .160 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| in Training | | | * | | | | | | |
| Educational level of household head | .145 | 1.73 | .086* | .084 | .713 | .479 | .225 | 1.25 | .250 |
| Membership 1 | .193 | 2.22 | .029* | .083 | -.550 | .584 | -.100 | -.456 | .662 |
| Membership 2 | - | - | - | - | - | - | -.193 | -1.137 | .293 |
| ***Farming Characteristics*** | | | | | | | | | |
| Land size | - | - | - | - | - | - | -1.16 | -4.88 | .002** |
| Irrigation use | -.110 | -1.22 | .227 | - | - | - | .184 | .988 | .356 |
| Purpose of growing maize | -.155 | -1.85 | .067* | - | - | - | .560 | 2.15 | .068* |
| Use of animal manure | .155 | 1.76 | .082* | - | - | - | -.134 | -.764 | .470 |
| Subsidy05 | -.143 | -1.69 | .093* | - | - | - | - | - | - |
| Subsidy06 | -.170 | -2.07 | .040* | - | - | | - | - | - |
| Plot_uncultivated | -.074 | -.875 | .384 | - | - | - | - | - | - |
| Plot_cultivated | | | | | | | .968 | 4.74 | .002** |
| Plot_location | - | - | - | -.383 | -3.47 | .001** | -.078 | -.464 | .656 |
| Distance06 | - | - | - | -.100 | -.898 | .373 | -.317 | -1.81 | .113 |
| Fertilizer Constraints | - | - | - | -.403 | -3.15 | .003** | - | - | - |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cattle ownership | - | - | - | -.199 | -1.35 | .184 | - | - | - |
| Harvest_Duration | .194 | 2.24 | .027* | .116 | .939 | .351 | .071 | .345 | .741 |
| ***Farmer perceptions*** | | | | | | | | | |
| Fertlizer_Percp | -.067 | -.805 | .423 | .187 | 1.41 | .164 | .544 | 2.35 | ..051** |
| Poverty_Percp | - | - | - | -.154 | -1.27 | .210 | .663 | 3.43 | .011** |
| Sample size | 357 | | | 135 | | | 138 | | |
| $R^2$ | .315 | | | .400 | | | .950 | | |

** variable is significant at the 5% level and * variable is significant at 10% level

The level of education of heads of households has been an important determinant of adoption of technologies (Asfaw *et al*, 2004; Jayne, *et al*, 2006). There was a significant positive relation between the amounts of fertilizer used and the education of the household head in Malawi only. The education of the head of household is associated with increased knowledge and therefore more educated people would be expected to be more knowledgeable on the use of fertilizers and on the recommended rates of fertilizer application. Waithaka *et al* (2007) found similar results in Kenya where the level of education of the household head increased the amount of fertilizer used. Households that had participated in agricultural training or exposure, either in terms of study tours to agricultural research centres or through direct training by NGOs, extension department or research were found to have a higher intensity of fertilizer use in Malawi as opposed to Zambia and Mozambique where training did not have a significant relationship with fertilizer use. Kelly *et al* (2003) also report increased use of fertilizers as a result of promotional strategies such as farmer training, demonstrations, participatory input testing in Nyanza province of Kenya. This was however not the case for Zambia and Mozambique where the relationship between education of head of household and training although positively related with fertilizer use was not significant. This is similar to studies conducted in Kenya and Tanzania, which found that the level of education of the household head was not significant in influencing the use of fertilizer (Ouma *et al*, 2002; Kaliba *et al*, 2000). Additionally, the results for Malawi can be attributed to that Malawi has a more intensive extension system than either Zambia and Mozambique and literature shows that extension service provision and extension intensity significantly and positively influences the use of inorganic fertilizers and adoption of other technologies generally (Kaliba *et al*, 2000; Okuro *et al*,2000). Furthermore, Malawi also had the highest proportion of respondents that had gone through primary and secondary education compared to Zambia and Mozambique.

Fertilizer use intensity was higher when members of households belonged to a group compared to when they did not. Membership in groups implies that farmers without enough resources to purchase fertilizer can pool such resources together for bulk purchases of fertilizer. Indeed this was reported in discussions with farmers in Malawi and especially those that did not access the subsidised fertilizers. Group extension has also become an important feature of extension services in the region and farmers that belong to groups are more likely to access extension and educational services compared to farmers working individually. Many development organizations and extension departments find it easier, and more cost effective to work with groups of farmers as opposed to individual farmers. Studies also show a relationship between social capital and adoption and diffusion of technologies and information (Isham, 2002; Frank *et al*, 2004; Padmaja *et a*l, 2006)

Availability of food and the performance of the previous season have implications on how farmers respond in the succeeding season. The number of months that the main food lasted (in this case maize) would elicit different responses in terms of how farmers prepare and act in the next season, depending on availability of resources.

Results from Malawi show that households with less food reserves used less fertilizer per acre than households with more food reserves. This agrees with our hypothesis and could be attributed to the fact that households with less food reserves used up their savings and other available resources to bridge the food deficit at the expense of purchasing inputs. Conversely it can also be stated that household's that use less fertilizer have lower levels of yields and hence less food reserves. Households with food deficits are also much poorer, have a low resource base and therefore not able to purchase capital intensive inputs.

Households' ability to purchase inputs including fertilizers is determined by their levels of resource endowment, assets, and disposable income (Crawford *et al*, 2003) and the poorer households have less of these resources at their disposal. Reardon *et al* (1995) view expenditure on production inputs as a function of this capacity to purchase and incentives. Such incentives could include output markets as well as policy incentives. The food shortage is more critical in Malawi compared to both Zambia and Mozambique which explains the non importance of the months of food availability in the use of fertilizers for these two countries. This may be attributed to that in this decade, Malawi faced its worst hunger crisis in more than 50 years despite having no catastrophic natural disasters like Mozambique or major political upheavals (Michael, 2002).

Farmers in Malawi and Zambia that grew maize mainly for cash were more likely to use more fertilizer per ha of land than those that were growing maize only for food. This agrees with other studies that have shown that much more fertilizer tends to go for high value cash crops (Kelly, 2005; Henao *et al*, 1999) because farmers usually assess the financial impact of applying fertilizer to a crop (Camara *et al*, 2006). In Malawi, farmers using manure were also more likely to use more fertilizer per acre of land. In Kenya, Waithaka *et al* (2007) found a positive relationship between the use of manure and fertilizer in Western Kenya. This could be due to the fact that households that use manure are more likely to own cattle and therefore are wealthier and able to afford to purchase larger quantities of fertilizer.

An unexpected result in the analysis was the negative relationship between farmers who had access to subsidized fertilizer in both 2005 and 2006 and intensity of fertilizer use. It was expected that farmers with access to subsidized fertilizers would have higher levels of fertilizer use intensity than those that had no access to the subsidy. In discussions with farmers, it was evident that farmers did not plan for the purchase of fertilizers in anticipation of the subsidy from the government. Lower quantities of fertilizer were supplied per farmer in the subsidy programme, and few farmers were able to purchase fertilizer to augment the subsidized fertilizer they received. In Malawi, farmers buy fertilizer at an equivalent of USD 22 per 50 kg of fertilizer while the subsidized fertilizer costs USD 6.8 per 50 kg bag. When preparing for the 2006/07 season, farmers had saved only enough money to buy the subsidized fertilizer and when this was not enough, they had no resources to purchase additional fertilizer leading to spreading of the available fertilizer over large areas of land. Another observation was the filtering of the fertilizer into Zambia and Mozambique. Farmers especially in Mozambique reported their source of fertilizer as subsidized fertilizer from Malawi. Some of the farmers who had access to subsidized fertilizers sold it off to their neighbors from Mozambique at a high price, thereby reducing the amounts used on their own farms. One of the issues reported by Crawford *et al* (2003) as potential causes of low input in the presence of government programs is the undercutting of the private sector which increases the uncertainty of input marketing and in turn could lead to low availability of inputs to smallholder farmers. While the fertilizer subsidy programme was implemented through a government affiliated organization in 2005, this was changed to include the private sector in 2006 with the aim of improving the distribution system and involving the private sector more. This greatly increased the access to subsidized fertilizers by farmers. Of the 357 households surveyed in Malawi, 21.8% received government subsidized fertilizer in 2005/6 growing season. This percentage increased to 46.2% for the 2006/7 growing season. While the programme reached more farmers, it did not significantly lead to increased intensity of fertilizer use.

The presence of savings had a positive and significant relationship with the intensity of use of fertilizers in both Zambia and Mozambique but not in Malawi. The total income by households was only significant for Zambia. The availability of savings by households enables them to purchase fertilizer and it is also likely that those households with savings are also wealthier and therefore able to purchase inputs. The location of the plot was positive and significant for Zambia indicating that farmers applied fertilizer more intensively in their main plot located in the valley bottoms compared to uplands. This is in agreement with the finding that when maize is grown more for cash, there is more intensity of fertilizer use. Maize that is mainly grown in the valley bottom in the winter season is sold off as green maize and is mainly for purposes of cash. This is as opposed to maize grown in the uplands during the main cropping season that is mainly for food and surplus is sold as grain.

The amount of land cultivated influenced fertilizer use in Mozambique but not in Malawi and Zambia. Farmers cultivating more land were likely to use less amounts of fertilizer than those cultivating less land. This could be mainly due to spreading of fertilizer across the large area vis intensifying and targeting use within a small area. Since land sizes across the three countries were not significantly different, this could be attributed to that generally Mozambique has a lower fertilizer use intensity than either Malawi or Zambia, with farmers in Mozambique applying less than 10 kg of fertilizer per hectare of arable land as compared to Malawi and Zambia where farmers apply between 10-50kg of fertilizer per hectare of arable land (Camara *et al*, 2006). The results in table 5, further show that a larger proportion of farmers in Mozambique (61.6 % and 53.6% in 2006/07 and 2005/06 seasons respectively) targeted only maize for fertilizer application as opposed to Malawi, where the majority (53.3% and 52.6% for 2006/07 and 2005/06 seasons respectively) applied fertilizer to other crops in addition to maize. For Zambia, the proportion of farmers targeting maize and other crops for fertilizer was not very different. In Mozambique, two important farmer perception variables were significant in determining intensity of fertilizer use. Households that did not perceive themselves as poor were likely to use more fertilizer per unit area compared to households that perceived themselves as poor. If households perceive themselves as poor, they are more likely to spend resources on basic necessities and immediate needs such as food and not on production inputs that only bring benefits at the end of the season. The perception of fertilizers as bad for the soil was also significant and positive. Farmers that perceived fertilizers were bad for the soil used less amounts of fertilizer per unit area. This underlies the importance of farmer perceptions in the promotion of input use.

## Work in progress

### Detailed characterization study on legume production, marketing and consumption, and nutritional status of rural households.

**P. Pypers[1], S. Kantengwa[2], K. Bishikwabo[3], J.P. Lodi-Lama[4], and B.Vanlauwe[1]**
*[1]CIAT-TSBF, Kenya; [2]CIALCA, Rwanda; [3]CIAT-Bukavu; [4]CIAT/INERA, Kinshasa*

A detailed characterization study was conducted during June and July 2007 in the mandate areas of the CIALCA / TSBF-CIAT project. This study complemented the earlier conducted baseline survey with quantitative information on aspects of legume cropping, soil fertility status, marketing of legume products and nutritional status of rural livelihoods. Households were randomly selected within the set of households interviewed during the baseline survey. Between 15 and 20 households in each of the 4 action sites in all mandate areas were fully characterized; nutritional status was evaluated in twice as many households. The characterization study entailed detailed questionnaires with farmers, soil and plant sampling, agronomic measurements in legume-grown fields, collection of essential socio-economic data for market chain analysis, anthropometric measurements in children between 2-5 years old, and an assessment of dietary intake and diversity. Data entry has currently been concluded and some preliminary analyses have been conducted (presented below). In-depth examination will involve factor and multivariate analysis. Soil and plant sample analysis are at this time pending.

*Legume production*

In each household, a map of the farm was drawn by the household head, indicating the location of the manure/compost storage system, livestock facilities and the different fields, relative to the homestead. The farmer was asked to specify the crops grown in the past two seasons. All fields cultivated by legumes were than highlighted and visited by an agronomist and a household member **(see Figure 4).** Detailed measurements were taken, including soil sampling, and measurement of crop and weed densities. Farmers gave details on crop management and inputs applied, appraised the soil fertility according to the local classification system and indicated the major constraints for crop production in the fields. Finally, compost and manure facilities were sampled for determination of organic matter quality and nutrient contents, and legume grain samples were taken for analysis of nutritional quality. Analysis results are pending.

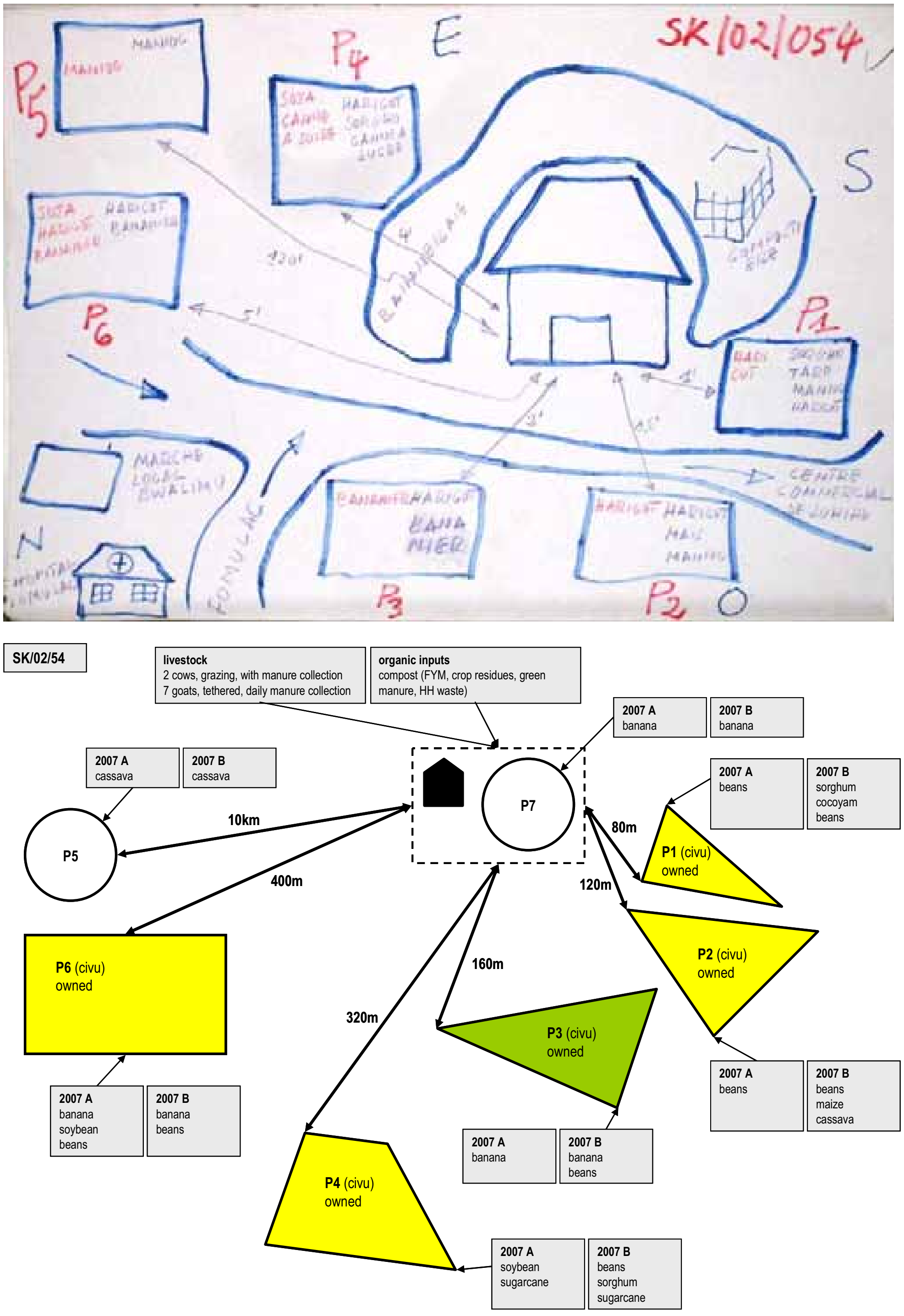


**Figure 4:** An example of a farm map of relatively wealthy household in Luhihi (Sud-Kivu), with livestock and manure facilities and 7 fields (all owned by the household). Five fields are cultivated by legumes (yellow fields are of medium fertility and green fields of high fertility, according to the farmer's appraisal).

Common legume systems differ between the mandate areas **(Figure 5)**. Legumes are commonly associated with cassava in Bas-Congo, with cassava and/or sweet potato in Sud-Kivu, and with cereals in Umutara. In Kibungo, legumes are frequently grown in association with both cereals and banana. Mixed cropping systems, with 3 or more crop types grown together in the same field are also commonly observed (except in Bas-Congo). These include mostly associations of root and tuber crops with cereals and legumes, and to a lesser extent banana with cereals and legumes (except in Kibungo). Legume mono-cropping is uncommon and almost never practiced during two consecutive seasons; farmers are aware of the disease accumulations, particularly for beans. Pure rotation systems are likewise rare, and some legumes are usually planted in association during the cereal season. Planting in line is very rarely practiced for legumes or cereals; seeds are usually simply broadcast.

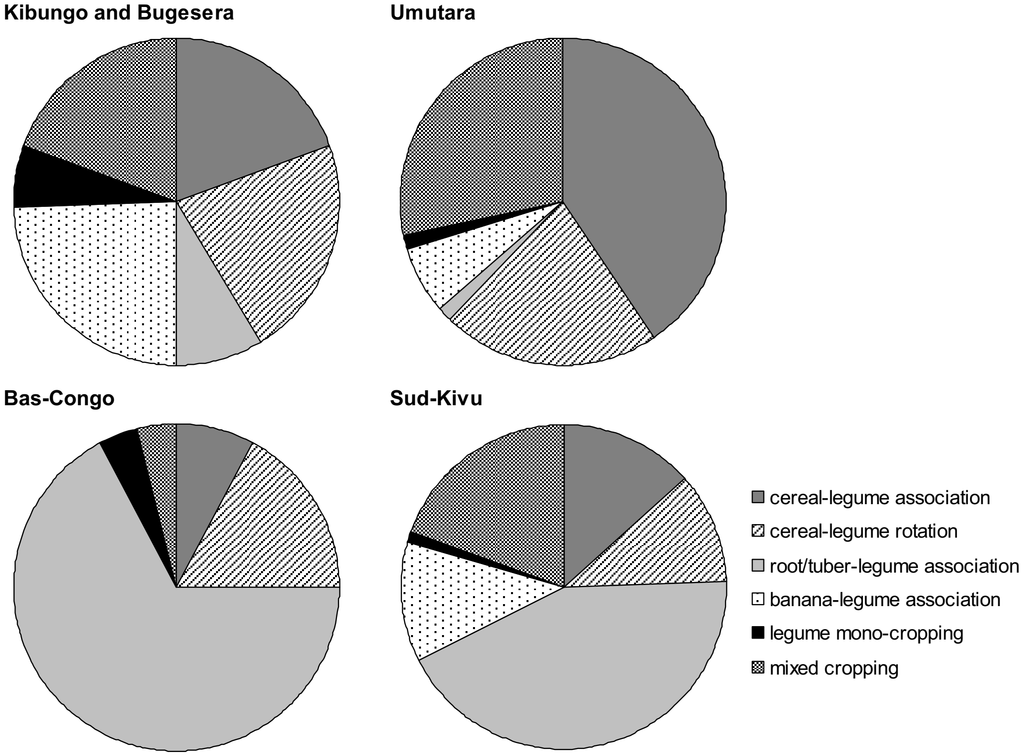


**Figure 5:** Relative importance of common legume production systems in the 4 mandate areas of the TSBF-CIAT project.

In Sud-Kivu and Rwanda, more than 70% of the legume-grown fields are positioned on slopes. While in Rwanda, conservation structures are common and well-maintained, in Sud-Kivu these are almost entirely absent. Almost 90% of the legume-grown fields on slopes are unprotected (only some physical embankments without hedgerows were observed), and two thirds of the fields show visible signs of erosion. Farmers however consider low soil fertility, drought and climatic variability as the major constraints for legume production.

*Legume commercialisation*

Legume varieties were characterized and farmers specified the minimal and maximal prices at which they sold their legume grains during the year on the local market. A preliminary analysis was conducted in Sud-Kivu **(Figure 6)**.

Groundnuts are primarily produced in Kabamba, and are sold at a much higher price (min. price = 1.6 \$ $kg^{-1}$) than beans and soybean (min price = 1.0 \$ $kg^{-1}$ and 0.6 \$ $kg^{-1}$, respectively). Maximal groundnut purchase prices in Kabamba are 1.9 \$ $kg^{-1}$ during periods of scarcity. Soybean prices differ between sites. Prices are lowest in Kabamba and Luhihi (on average 0.65 \$ $kg^{-1}$), where soils are relatively more fertile and soybean is more commonly produced than in the Walungu area (Lurhala and Mwegerera). Minimal soybean purchase prices in the Walungu area are almost twice as high as on the northern axis (Kabamba and Luhihi). For beans, purchasing prices fluctuate around 1 \$ $kg^{-1}$, and are slightly lower in Lurhala. Maximal price increases during periods of scarcity occur in Kabamba (up to 0.5 \$ increase $kg^{-1}$). Price differences in space and time open up a number of marketing opportunities through transportation and storage, allowing producers to sell where and when the price is highest. Moreover, prices depend on grain traits such as size and colour. Prices for grains of the preferred color (red and white) are higher than for less-preferred colors (black), and usually increase for larger grain sizes.

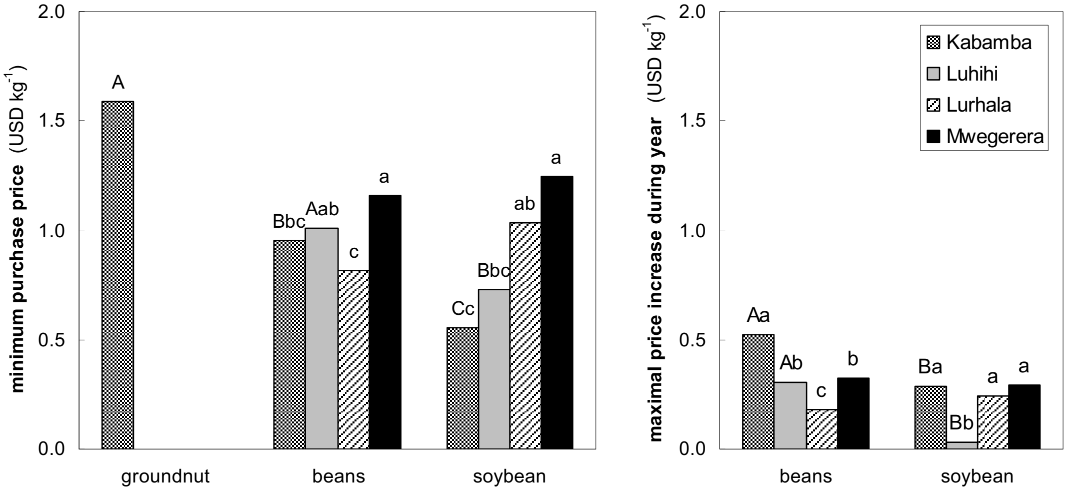


**Figure 6** Minimal legume grain purchasing prices (left) and price increases during periods of scarcity (right) as reported by farmer-producers in the 4 action sites in the Sud-Kivu mandate area. Letter labels indicate a significant ($P<0.05$) difference in price between species (capital letters) or sites (lower-case letters).

*Nutritional status of rural households*

In Sud-Kivu, malnutrition is very prevalent in younger children; more than 30% of 2- to 3-year-old children show at least mild symptoms of marasmus or suffer from kwashiorkor **(Figure 7)**. Lack of muscular tissue, swollen abdomen, wrinkled or flaky skin and scanty, pale hair were the most commonly observed symptoms. Relatively less symptoms of malnutrition were observed in Rwanda (across both mandate areas). In Rwanda, malnutrition was more pronounced in girls than in boys, while in Sud-Kivu, symptoms of marasmus or kwashiorkor were more often observed in boys than in girls.

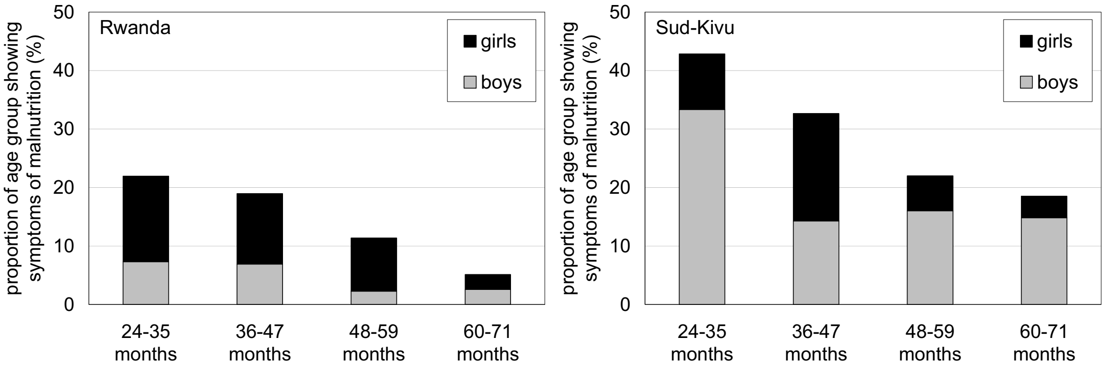


**Figure 7:** Prevalence of malnutrition symptoms (marasmus/kwashiorkor) in 2- to 5-year-old children of rural households in Rwanda and Sud-Kivu.

Anthropometric measures were taken in 2-to 5-year-old children, and included the weight, height and mid-upper-arm circumference (MUAC). In Sud-Kivu, depending on the measures and cut-off points used, between 2 and 12% of the children suffer moderate acute malnutrition, and between 14 and 25% are at risk of malnutrition **(Figure 8).** In Rwanda, anthropometric measures identified very few children with moderate malnutrition, and up to about 10% were at risk. Estimates of malnutrition rates tend to be larger using MUAC measurements than WFH measurements (Bairagi and Ahsan, 1998).

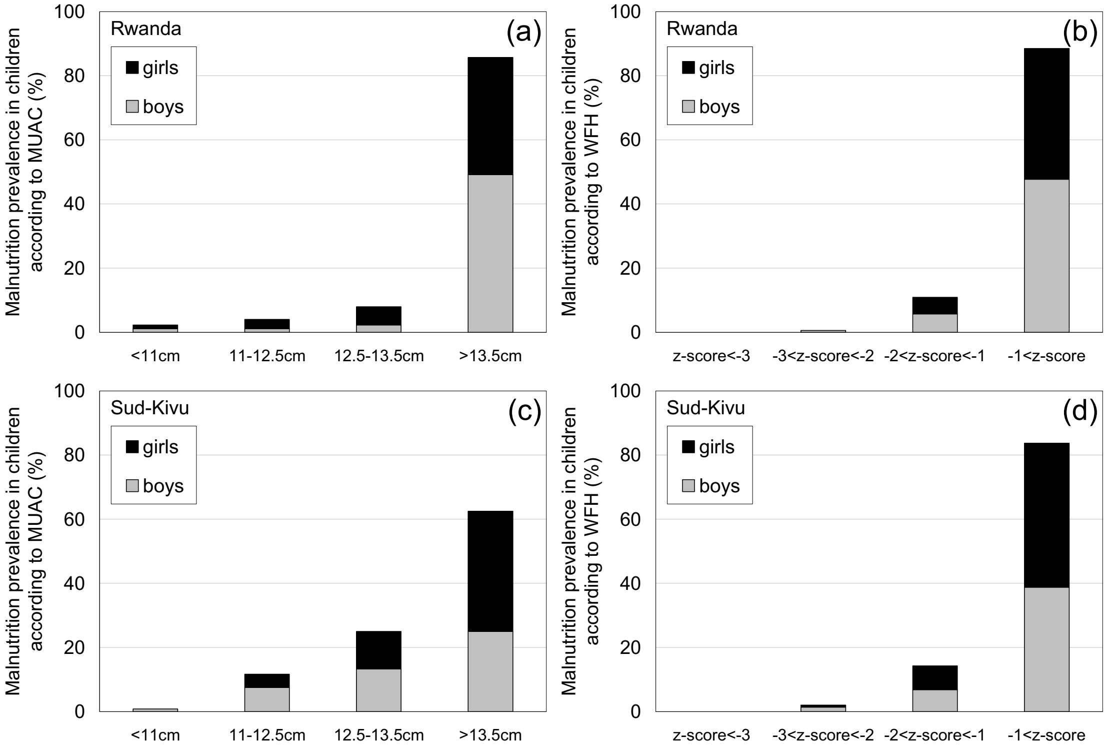


**Figure 8**: Malnutrition prevalence according to (a,c) mid-upper-arm circumference (MUAC) and (b,d) weight-for-height (WFH) in 2- to 5-year-old children of rural households in Sud-Kivu and Rwanda. Categories signify (from left to right): severe, moderate, mild and absent acute malnutrition (Lancet and Morley, 1974); z-scores are relative to the median of the respective populations.

*Legume consumption in Sud-Kivu*

Diets of 2- to 5-year-old children were determined by asking mothers to recall the foods given to their child during the past week and month. Presented below are the data for the action sites in the Sud-Kivu mandate area.

Legumes constitute the principal source of protein for children in Sud-Kivu. In Lurhala and Mwegerera, more than 50% of the children consume meat- or fish-derived protein less than once a week, and usually only once or twice a month **(Figure 9).** About 30% of the households feed their children with meat or fish once or twice a week. In Kabamba and Luhihi, which are close to the lakeside, consumption of small fish ('frétins') is very common, but meat is less frequently eaten.

The consumption of eggs is very rare in all sites. Among the four legumes grown in the area, soybean and bean are the most important legumes in the diets of young children. Cowpea is rather uncommon and groundnut is principally grown as a cash crop. In Luhihi, a productive soybean area, about three quarters of the children are fed with soybean more than five times a week **(Figure 10).** Soybean is either prepared as soymilk, tea, or porridge (commonly mixed with maize and/or sorghum). In the other sites, soybean remains an important constituent of young children and is consumed on average 3-4 times per week. Beans are also important, and fed at least once or twice a week in 70% of the households.

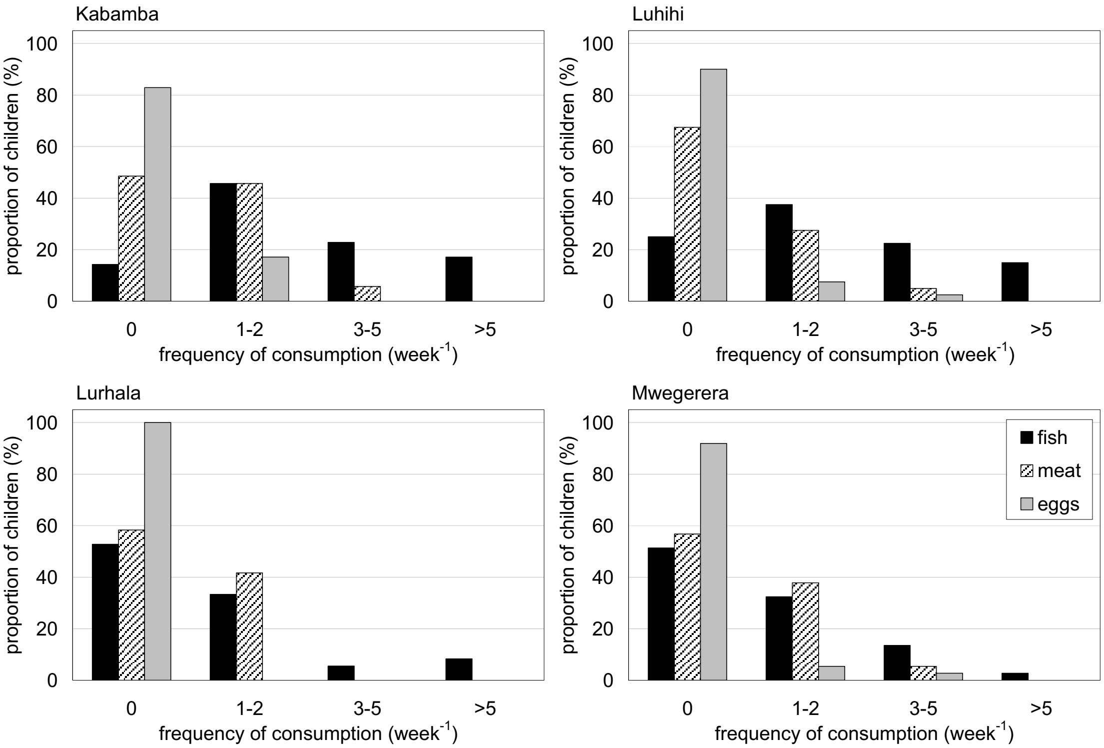


**Figure 9:** Frequency of consumption of meat, fish and eggs by 2- to 5-year-old children in the 4 action sites in the Sud-Kivu mandate area**.**

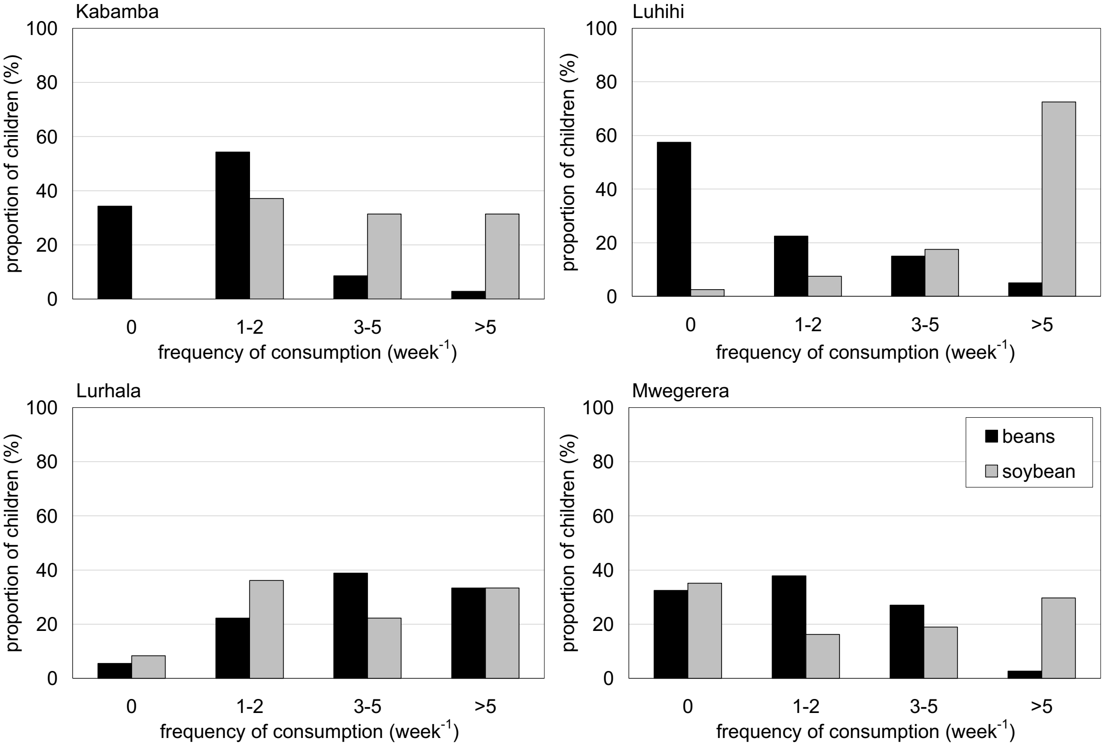


**Figure 10**: Frequency of consumption of beans and soybean by 2- to 5-year-old children in the 4 action sites in the Sud-Kivu mandate area.

# Output target 2009

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

## Published work

**Andren[1], O., Kihara[2], J., Bationo[2], A., Vanlauwe[2], B., Katterer[1], T. Soil climate and decomposer activity in sub-Saharan Africa, estimates from standard weather station data – used in soil carbon balance calculations. In: Advances in integrated soil fertility management in sub Saharan Africa: challenges and opportunities, (eds) Bationo, A., Waswa, B., Kihara, J. and Kimetu, J. Ambio 36, 2007, 379-386.**

*[1]SLU, Sweden; [2]CIAT-TSBF, Kenya*

**Abstract:** Soil biological activity was calculated on a daily basis, using standard meteorological data from African weather stations, a simple soil water model, and commonly used assumptions regarding the relations between temperature, soil water content, and biological activity. The activity factor re_clim is calculated from daily soil moisture and temperature, thereby taking the daily interaction between temperature and moisture into account. Annual mean re_clim was normalized to 1 in Central Sweden (clay loam soil, no crop), where the original calibration took place. Since soils vary in water storage capacity

and plant cover will affect transpiration, we used this soil under no crop for all sites, thereby only including climate differences. The Swedish re_clim value, 1, corresponds to ca. 50% annual mass loss of, e.g., cereal straw incorporated into the topsoil. African mean annual re_clim values varied between 1.1 at a hot and dry site (Faya, Chad) and 4.7 at a warm and moist site (Brazzaville, Congo). Sites in Kenya ranged between re_clim ¼ 2.1 at high altitude (Matanya) and 4.1 in western Kenya (Ahero). This means that 4.1 times the Swedish C input to soil is necessary to maintain Swedish soil carbon levels in Ahero, if soil type and management are equal. Diagrams showing daily re_clim dynamics are presented for all sites, and differences in within-year dynamics are discussed. A model experiment indicated that a Swedish soil in balance with respect to soil carbon would lose 41% of its soil carbon during 30 y, if moved to Ahero, Kenya. If the soil was in balance in Ahero with respect to soil carbon, and then moved to Sweden, soil carbon mass would increase by 64% in 30 y. The validity of the methodology and results is discussed, and re_clim is compared with other climate indices. A simple method to produce a rough estimate of re_clim is suggested

## Completed work

### The prospects of reduced tillage in tef (Eragrostis tef Zucca) in Gare Arera, West Shawa Zone of Oromiya, Ethiopia. Soil Tillage Research , In Press

**B. Tulema[1], J.B. Aune[2], F.H. Johnsen[2], and B. Vanlauwe[3]**

*[1]Holeta Research Institute, Ethiopia; [2]Noragric, Norway; [3]CIAT-TSBF, Kenya*

**Absract:** Soils in Ethiopia are traditionally ploughed repeatedly with an oxen-drawn plough before sowing. The oxen ploughing system exposes the soil to erosion and is expensive for farmers without oxen. This study was undertaken to assess agronomic and economic impacts of alternative, reduced tillage methods. Field experiments were carried out on a Vertisol and a Nitisol for two years to study the effect of zero tillage, minimum tillage, conventional tillage, and broad bed furrows (BBF) on the yield of tef (*Eragrostis tef* Zucca). No significant differences in tef biomass and grain yields were observed between the treatments on both soils in the first year. In the second year, zero tillage significantly reduced plant height, biomass and grain yield. No difference between single plough, conventional, and BBF was observed. Grass weed population was highest on zero tillage and lowest on BBF on both soils. Total cost varied significantly between zero tillage and the other tillage systems. Pre-planting land preparation and weeding costs of tef were highest for zero tillage. Highest and lowest gross margins were obtained on BBF and zero tillage, respectively. No difference was observed in gross margin between minimum tillage and conventional tillage. Minimum tillage is an interesting option, particularly for female-headed households as it reduces the tillage cost. It may also improve overall productivity of the farming system because it allows partial replacement of oxen with cows and reduces soil erosion.

**Work in progress**

Indicators of Soil Biological Quality (tentative title): Analysis of the inventory data on belowground biodiversity gathered from 11 benchmark areas in seven countries, gathered during the first phase of the CSM-BGBD will result in the identification of soil biological quality indicators and indicator of loss of soil biodiversity. These indicators are intended to be used for management decision regarding the soil biological quality or soil health. Publication is expected to be submitted in 2008.

## Output target 2009

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

**Work in progress**

### Relationship between soil fertility and nutritional quality of bio-fortified bean grains: a G by E analysis of Fe contents in grains of beans grown in Sud-Kivu and Umutara.

**P. Pypers[1], D. Kagabo[2], J. Mbikayi[3], and B.Vanlauwe[1]**

*[1]CIAT-TSBF, Kenya; [2]ISAR, Rwanda; [3]INERA, Rwanda*

Legume germplasm evaluation trials were conducted in the framework of the CIALCA / TSBF-CIAT project. In these trials, 27 bush bean and 9 climbing bean varieties, along with the local variety, were tested by 2 farmer associations in 4 sites in Sud-Kivu, DRC and in 4 sites in Umutara, Rwanda (16 associations in total). In each association, separate blocks were set up with a control and a treatment with goat manure application at 5 t dry matter (DM) $ha^{-1}$. After harvest, a representative sample of grains was taken, oven-dried and manually ground using an agate mortar and pestle. A subset of the grain samples was analyzed for Fe contents using radial ARL ICP-AES by ARI laboratories, Adelaide.

A preliminary analysis was conducted by fitting following general linear model:

$$Fe\_C_{a,t,g} = \mu + \alpha_a + \beta_t + \gamma_g + \theta_{a,t} + \theta'_{g,t} + \varepsilon_{a,t,g}$$

with $Fe\_C_{a,t,g}$ = grain Fe content for genotype ‘g’ in association ‘a’ with treatment ‘t’ [mg Fe $kg^{-1}$], $\mu$ = grand mean, $\alpha_a$ = environment (association) mean deviations, $\beta_t$ = treatment mean deviations, $\gamma_g$ = genotype mean deviations, $\theta_{a,t}$ = association × treatment interaction residuals, $\theta'_{g,t}$ = genotype × treatment interaction residuals and $\varepsilon_{a,t,g}$ = the error term; the association CINAMULA (Lurhala) was excluded from the model as no observations in the control treatment were available.

Analysis of variance demonstrates that grain Fe content is largely determined by environment (association) and genotype and unaffected by FYM application **(Table 4)**. Genotypic and environmental effects alone can explain 17 and 44% of the total variation, respectively. Interaction effects between genotype and environment are part of the error term (35.1% of the total variation).

**Table 4:** ANOVA for significance of genotype, environment (association), treatment and environment × treatment and genotype × treatment interaction effects on Fe contents in bean grains

| source of variation | df | SS | MS | *F*-value | *P*-value | % of total SS |
|---|---|---|---|---|---|---|
| total | 214 | 27684.3 | | | | |
| model | 53 | 17971.4 | 339.1 | 5.62 | <0.0001 | 64.9 |
| environment (association) | 10 | 12304.1 | 1230.4 | 20.40 | <0.0001 | 44.4 |
| treatment | 1 | 0.4 | 0.4 | 0.01 | 0.9335 | 0.0 |
| genotype | 16 | 4682.9 | 292.7 | 4.85 | <0.0001 | 16.9 |
| environment × treatment | 10 | 534.3 | 53.4 | 0.89 | 0.5480 | 1.9 |
| genotype × treatment | 16 | 449.6 | 28.1 | 0.47 | 0.9599 | 1.6 |
| error | 161 | 9712.9 | 60.3 | | | 35.1 |

Bean varieties Marungi and ARA4 generally contained highest grain Fe contents while BRB194, CIM9314-36 and Kiangara contained lowest grain Fe contents **(Table 5)**. Highest Fe contents were observed in the ALEMALU and APACOV associations (which are rather infertile sites), while lowest Fe contents were observed in the MAENDELEO, RUSINAME and IRIBA associations (which are rather fertile sites).

**Table 5**: Adjusted grain Fe content means and standard errors for the different bean varieties (across associations) and for the different associations (across varieties)

| species | variety | adj. mean | st. error |
|---|---|---|---|
| BB | Marungi* | 74.06 | 1.91 |
| BB | ARA4* | 72.91 | 1.85 |
| BB | ZAA5/2 | 72.82 | 2.11 |
| BB | ECAPAN021 | 72.44 | 2.04 |
| CB | VCB81013* | 72.36 | 2.80 |
| BB | HM21-7* | 71.90 | 2.03 |
| BB | ZKA93-10m* | 69.77 | 1.80 |
| CB | MLV06* | 69.63 | 2.99 |
| BB | AFR708 | 68.47 | 2.10 |
| BB | CODMLB003* | 68.28 | 2.19 |
| CB | AND10* | 68.08 | 2.39 |
| CB | VCB81012* | 67.78 | 3.01 |
| CB | local variety CB | 67.16 | 3.00 |
| BB | local variety BB | 65.50 | 2.19 |
| BB | BRB194* | 61.95 | 2.19 |
| BB | CIM9314-36 | 59.64 | 2.04 |
| CB | Kiangara* | 58.51 | 2.68 |

| association | action site | adj. mean | st. error |
|---|---|---|---|
| ALEMALU | Lurhala | 82.55 | 3.11 |
| APACOV | Burhale | 77.58 | 1.64 |
| DUFATANYE | Nyakigando | 73.24 | 1.39 |
| TWISUNGANE | Rugarama | 71.53 | 1.90 |
| RHUBEHAGUMA | Luhihi | 71.00 | 2.01 |
| ABAGWASINYE | Burhale | 70.26 | 4.19 |
| TUUNGANE | Kabamba | 64.84 | 2.00 |
| ISOKO Y'UBUMWE | Kabarore | 62.59 | 1.44 |
| MAENDELEO | Kabamba | 59.52 | 1.74 |
| RUSINAME | Luhihi | 59.36 | 1.68 |
| IRIBA | Murambi | 58.93 | 1.77 |

The AMMI model analyses G×E interactions by combining ANOVA (with additive parameters) and PCA (with multiplicative parameters). As it requires a fully balanced dataset (i.e. each genotype in each environment), only a sub-selection of the full dataset was submitted. This sub-selection included 10 bush bean varieties (AFR708, ARA4, BRB194, CIM9314-36, CODMLB003, ECAPAN021, HM21-7, Marungi, ZAA5/2 and ZKA93-10m/95) in 7 associations (APACOV, RHUBEHAGUMA, RUSINAME, TUUNGANE, MAENDELEO, ISOKO Y'UBUMWE and DUFATANYE. This sub-selection includes both some of varieties with the highest and lowest grain Fe contents but does not include the associations with highest (ALEMALU) or lowest (IRIBA) grain Fe contents. Applying the simple regression model to the data sub-selection shows that purely genotypic effects remain significant (explaining 33% of the total variation) but purely environmental effects become insignificant ($P<0.37$). The AMMI analysis can be used to study G×E interactions in the data sub-selection; however, it does not take full account of the environmental variability in the entire dataset. As manure application did not significantly affect grain Fe contents, treatments were considered as replications in the AMMI analysis. Missing values (18) were predicted using the model described in the preliminary analysis (i.e. assuming no G×E interaction) to balance the dataset.

The AMMI model is described as:

$$Fe\_C_{a,g} = \mu + \alpha_a + \gamma_g + \sum_{n-1}^{N} \lambda_n \zeta_{g,n} \eta_{a,n} + \rho_{a,g} + \varepsilon_{a,g}$$

with $Fe\_C_{a,g}$ = grain Fe content for genotype 'g' in association 'a' [mg Fe $kg^{-1}$], $\mu$ = grand mean, $\alpha_a$ = environment (association) mean deviations, $\gamma_g$ = genotype mean deviations, N = the number of singular value decomposition (SVD) axes retained in the model, $\lambda_n$ = singular value for SVD axis n, $\zeta_{g,n}$ = genotype singular vector value for SBD axis n, $\eta_{a,n}$ = association singular vector value for SVD axis n, $\rho_{a,g}$ = AMMI residuals, and $\varepsilon_{a,g}$ = the error term.

The AMMI analysis shows that grain Fe contents are significantly affected by environment (association) and genotype, which explained 5 and 46% of the model variation, respectively

**(Table 6)**. G×E interaction accounted for 49% of the total model variation. Two IPCA factors could significantly explain 74% of the G×E interaction variation.

**Table 6:** AMMI analysis of variance for significance of genotype, environment (association) and genotype × environment (association) interaction effects on grain Fe contents, and the partitioning of interaction effects into AMMI axes

| source of variation | df | SS | MS | *F*-value | *P*-value | % of G×E SS |
|---|---|---|---|---|---|---|
| Total | 139 | 17636 | 126.9 | | | |
| Model | 69 | 12656 | 183.4 | 2.41 | 0.0003 | |
| Genotype | 9 | 5795 | 643.9 | 8.45 | <0.0001 | |
| environment (association) | 6 | 615 | 102.5 | 3.96 | 0.0020 | |
| Block | 7 | 181 | 25.9 | 0.34 | 0.9326 | |
| genotype ×environment | 54 | 6246 | 115.7 | 1.52 | 0.0553 | |
| IPCA1 | 14 | 2496 | 178.3 | 2.34 | 0.0113 | 40.0 |
| IPCA2 | 12 | 2126 | 177.2 | 2.33 | 0.0156 | 34.0 |
| Residuals | 28 | 1623 | 58.0 | 0.76 | 0.7846 | 26.0 |
| Error | 63 | 4799 | 76.2 | | | |

The IPCA factors were tested for correlation with soil characteristics (pH, org. C, total N, extractable P and exchangeable bases). IPCA 1 was found to be negatively correlated with soil organic C and total N contents (r = -0.71 and -0.77 with *P*-values 0.07 and 0.04, respectively). Environments with higher IPCA 1 scores would thus be less fertile environments with lower organic C and total N contents. Sites with higher soil organic C and total N contents were RUSINAME, RHUBEHAGUMA, MAENDELEO and APACOV. Sites with lowest soil organic C and total N contents were ISOKO Y'UBUMWE and DUFATANYE.

The AMMI biplot **(Figure 11)** shows 71% of the model variation with 46%, 5% and 20% due to genotype, environment and G×E interaction (IPCA 1 only), respectively. For any G-E combination in the biplot, the AMMI-calculated grain Fe content can be estimated by adding the G and E means minus the grand mean (69.9 mg Fe kg$^{-1}$) to the product of the G and E IPCA 1 scores. For variety BRB194 grown in ISOKO Y'UBUMWE for example, this becomes:

$Fe\_C_{AMMI}$ = 76.0 (G mean) + 68.7 (E mean) – 69.9 (grand mean) + 2.99 (G IPCA 1 score) × 4.37 (E IPCA 1 score)

= 87.9 mg Fe kg$^{-1}$

This fits the observed value $Fe\_C_{observed}$ = 90.3 mg Fe kg$^{-1}$. Actual calculated values by the AMMI model (in this case: 88.2 mg Fe kg$^{-1}$) may differ slightly from these simple calculated values as the AMMI model also considers the G×E interaction effect accounted for by ICPA 2 (17% of the model variation).

This example illustrates the positive interaction between this genotype and environment. Inversely, growing AFR708 in the same association would lead to a negative interaction.

Genotypes can be selected based on high Fe contents and/or on stability (i.e. less variable grain Fe contents across environments). When selecting genotypes for high Fe contents, genotypes need to be chosen with high means and positive interaction with a given environment. For ISOKO Y'UBUMWE, TUUNGANE and DUFATANYE, these genotypes would thus be BRB194 and ZKA93-10m, while for MAENDELEO, RHUBEHAGUMA and APACOV, these genotypes would be ARA4 and AFR708. Varieties with stable grain Fe contents across environments are ECAPAN021 and ZAA5/2. However, these varieties both have low Fe contents (below the grand mean). The most suitable variety across all environments would thus be ARA4, with the highest mean Fe content (80.0 mg Fe kg$^{-1}$) and a relatively small ICPA 1 score (-1.56 mg Fe kg$^{-0.5}$), indicating relatively high stability.

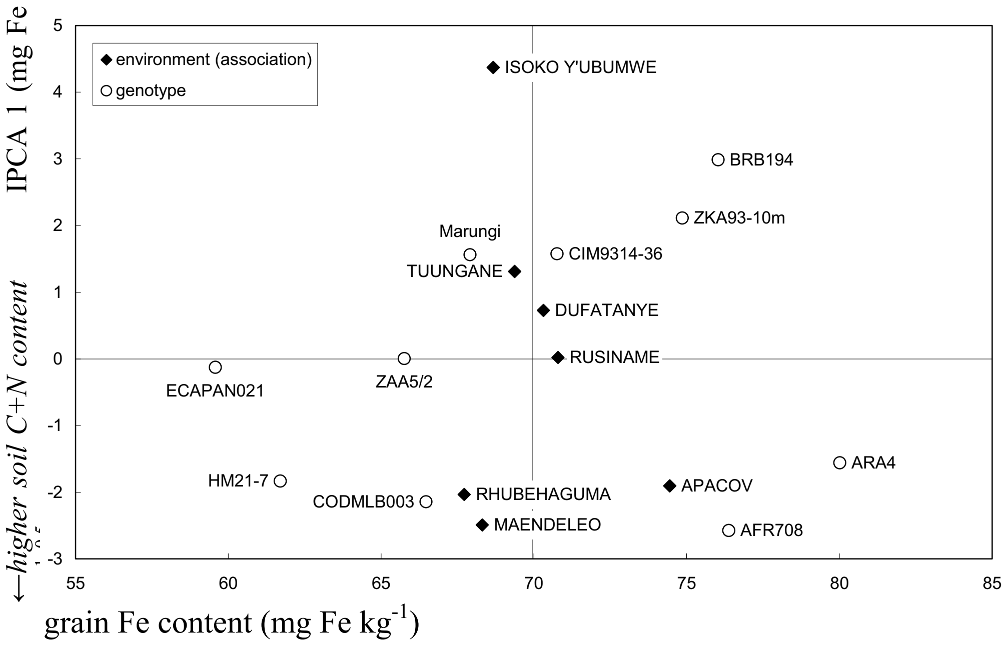


**Figure 11:** AMMI biplot showing the main and IPCA 1 effects of both genotypes and environments (associations) on grain Fe content; an estimate of the G×E interaction effect for a specific genotype – environment (association) combination equals the product of their corresponding IPCA1 scores.

Identification of varieties with highest Fe contents for specific environments can also be done through plotting the AMMI-calculated grain Fe contents for each genotype in function of the environments' IPCA 1 scores **(Figure 12)**. Genotypes thus become ranked for grain Fe content in each environment. Varieties ARA4, AFR708, ZKA93-10m and BRB194 are amongst the 4 varieties with highest Fe contents in most associations **(Table 7)**. Except for

AFR708, these are known biofortified varieties with elevated Fe and/or Zn contents in the grains. These varieties also show opposite trends in grain Fe content versus IPCA 1 score relationship: while BRB194, and ZKA93-10m show increasing grain Fe contents with increasing IPCA 1 score (decreasing soil C and N content), ARA4, AFR708 and CODMLB003 show decreasing grain Fe contents with increasing IPCA 1 scores (increasing soil C and N content).

**Table 7:** Varieties ranked following grain Fe contents based on AMMI-calculated values in each environment; varieties marked with an asterisk (*) are known biofortified varieties with elevated grain Fe and/or Zn contents.

| Association | action site | 1st variety | 2nd variety | 3rd variety | 4th variety |
|---|---|---|---|---|---|
| APACOV | Burhale | ARA4* | AFR708 | CIM9314-36* | CODMLB003* |
| RHUBEHAGUMA | Luhihi | ARA4* | AFR708 | ZKA93-10m* | BRB194* |
| RUSINAME | Luhihi | ARA4* | ZKA93-10m* | BRB194* | AFR708 |
| TUUNGANE | Kabamba | ZKA93-10m* | BRB194* | ARA4* | AFR708 |
| MAENDELEO | Kabamba | ARA4* | AFR708 | CODMLB003* | ZKA93-10m* |
| ISOKO Y'UBUMWE | Kabarore | BRB194* | ZKA93-10m* | CIM9314-36* | ARA4* |
| DUFATANYE | Nyakigando | CIM9314-36* | ARA4* | AFR708 | Marungi* |

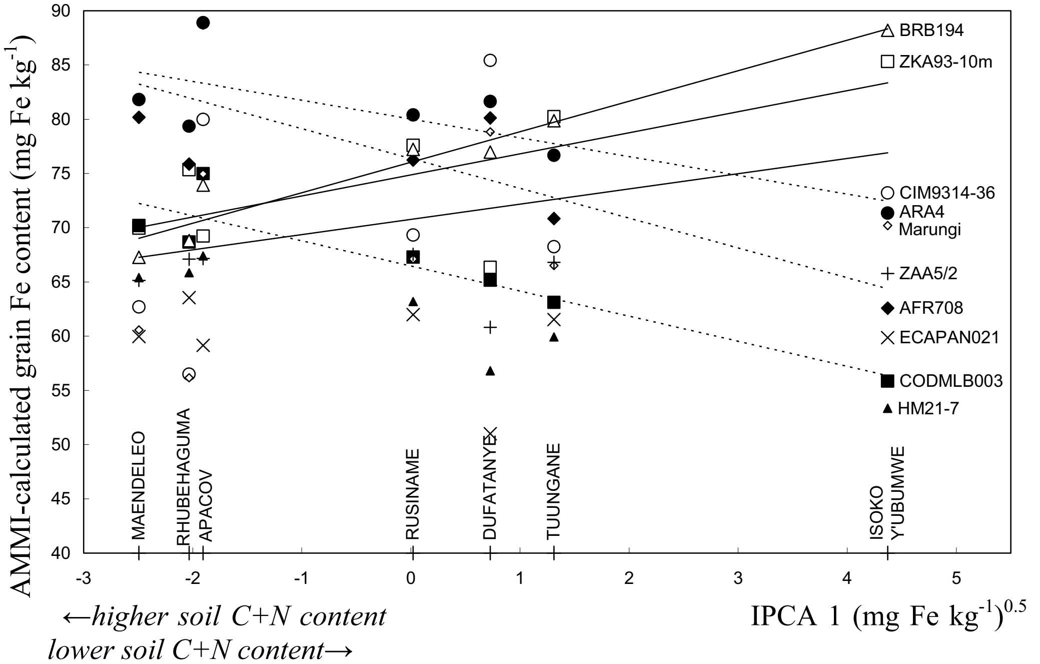


**Figure 12:** Calculated grain Fe contents of 10 bean varieties based on the AMMI model equation across environment IPCA 1 scores. Full lines are regressions for varieties BRB194, ZKA93-10m and CIM9314-36; dotted lines are regressions for varieties ARA4, AFR708 and CODMLB003.

## Conclusion

A simple linear regression model applied to the entire dataset showed that 44% of the total variation in grain Fe contents could be attributed to purely environmental effects, while 17% is related to purely genotypic effects. An AMMI analysis on selected varieties and environments (associations) was conducted to study G×E interaction effects. Although the sub-selection did not represent the environmental variability of the entire dataset, it revealed significant G×E interaction effects accounting for 35% of the total variation in the data sub-selection. This demonstrates the necessity of taking G×E interactions into account when selecting bean varieties for high grain Fe contents.

The variety ARA4 can be recommended as a genotype with high Fe contents (73 mg Fe kg$^{-1}$) across environments. However, other varieties such as BRB194 and ZKA93-10m have higher grain Fe contents in specific environments, likely characterized by less fertile soils with lower organic C and total soil N contents.

ARA4, a biofortified bean variety with stable and high Fe contents.

## Output target 2009

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

## Output target 2010

- ***The role of soil organic matter in regulating soil-based functions underlying fertilizer use efficiency and crop production understood***

### Published work

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

*[1]CIAT-TSBF, Kenya; [2]University of Cornell, USA*

**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 sink 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.

### P. Mapfumo[1], F. Mtambanengwe[1], and B. Vanlauwe[3], 2007 Organic matter quality and management effects on enrichment of soil organic matter fractions in contrasting soils in Zimbabwe. Plant and Soil 296, 2007, 137-150.

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**Abstract:** Maintenance of soil organic matter (SOM) at levels that sustain optimal supply of soil nutrients and enhance efficiency of externally added fertilizers is a major challenge for smallholder farming systems of southern Africa. A study was conducted to quantify the interactive effects of organic resource quality and management on SOM formation and subsequent maize yields under contrasting soil types. Crotalaria juncea L., Calliandra calothyrsus Meissn, cattle manure, maize (Zea mays L.) stover and Pinus patula Schiede and Schltdl. And Cham. sawdust were applied at 1.2 and 4 t C ha_1 at Domboshawa and Makoholi Experimental Stations, simulating some of the soil amendments commonly available on smallholder farms. Soils at Domboshawa are sandy–clay loams with 220 g clay kg_1 while the sandy soils at Makoholi had <100 g clay kg_1. At 12–14 weeks after incorporation, organic resource quality effects on particulate organic matter (POM) C enrichment were most significant ($p < 0.01$) in the macro-POM (250–2,000 mm diameter) fraction of both soil types constituting 15–30% of total soil C on coarse sand soil and 5–10% on sandy clay loam soils. The highest increases were under C. calothyrsus, manure and sawdust treatments. There was evidence of sub-soil enrichment under these two treatments on sandy soils at different sites. While no significant treatment effects were observed on the size of organo-mineral fraction, there was a significant ($p < 0.05$) separation of treatments in terms of potential mineralizable N from the same fraction. On coarse sands, organo-mineral fraction under medium to high-quality materials such as manure and C. juncea released *50 mg N kg_1, compared to 8–18 mg N kg_1 from sawdust and maize stover, suggesting that such materials enhanced the N-supply capacity of this fraction without necessarily increasing its size. The same trends were observed under sandy clay loams although, in contrast to coarse sands, the high-quality materials released no more than 25 mg N kg_1, suggesting that the added C was protected against short-term mineralization. These contrasting properties were also reflected in maize yield patterns. On sandy clay loams, a significant linear relationship between maize yield and the amount of mineralizable N in the macro-POM fraction (R2 = 0.50; $p < 0.01$) was evident, while the best predictor for maize yield on coarse sands was the amount of mineralizable N from the organo-mineral fraction (R2 = 0.86). We concluded that maize productivity on contrasting soil types hinges on different soil organic fractions and therefore require different management strategies. Sustainability of cropping on sandy soils is likely to depend on a regular supply of high-quality C materials, which enhance the nutrient supply capacity of the small organo-mineral fraction. Under the relatively C protective sandy clay loams, it is apparently the size of the macro-POM fraction which largely determines crop yields in the short-term.

## Work in progress

### Challenges for replenishing soil fertility in depleted fields: evidence from long-term trials in Zimbabwe.

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Gradients of decreasing soil fertility with increasing distance from homesteads commonly occur on smallholder farms in sub-Saharan Africa due to differential resource management. A study was conducted for five seasons (2002-2006) on fields closest to homesteads (homefields) and outlying fields (outfields) of two smallholder farms on a sandy and clayey soils to assess maize yields after applying 100 kg N $ha^{-1}$ $yr^{-1}$ with different rates of P (0, 30, 50 kg $ha^{-1}$ $yr^{-1}$) from single super phosphate (SSP) or cattle manure. In the first four 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 large amounts of manure (~17 t manure $ha^{-1}$ $yr^{-1}$) for three seasons was necessary to significantly increase maize yields on the sandy outfields. There were no significant grain yield responses to addition of fertilizer N and SSP in the outfields over the first four seasons. In the fifth season, Ca and micronutrients (Zn, Mn, B) were added to assess of the potential to increase maize yields in these fields by targeted micronutrient fertilizer application, but their effects were masked by poor rainfall. A cost-benefit analysis revealed that more than five years were required for farmers to off-set the costs of replenishing soil fertility in degraded fields by applying large amounts of manure.

### Changes in Soil Organic Matter as Influenced by Organic Residue Management Regimes in Selected Experiments in Kenya, Challenges and opportunities, 457-469

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**Abstract:** The failure to understand the dynamics of soil organic matter (SOM) is a major limitation to the sustainability of smallholder production systems that predominantly relied on organic resources for the maintenance of soil fertility. This study evaluated the influence of organic resource management on SOM in three selected experiments in central and western highlands of Kenya. Results showed that soil carbon (C), nitrogen (N) and carbon-13 ($^{13}$C) values in the three experiments were depending on the amounts of the organic residues applied as well as the duration of application indicating that organic residue management practices have a profound impact on the final contribution to the SOM pools. Kabete experiment had the narrowest C, N and $^{13}$C values pointing to its young age as well as the low quantity of the organic residues applied. On the other hand, Embu experiment had soil C values above the critical level of 2.0% indicating a positive effect of continued application of organic residues. In all the three sites, aggregate mineral fraction (MF) size distribution were dominated by macroaggregates (250–500 µm and >500 µm) which on average accounted for about 72%, 65% and 69% of the dry soil weight for Maseno, Kabete and Embu experiments, respectively. Similarly higher proportions of aggregate light fractions (LF) C and N were observed in macroaggregate fractions for the three experiments with organic treatments having higher proportions. The $^{13}$C signatures of the LF in the macroaggregates (>250 µm) were more negative as compared to the $^{13}$C values in the microaggregate (53–250 µm) LF suggesting a more C contribution from C3 vegetation to the most recently incorporated SOM pool

### Organic resource quality influences short-term aggregate turnover and soil organic carbon dynamics.

**P. Chivenge[1], B. Vanlauwe [2], R. Gentile[1] and J. Six[1]**

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#### Introduction

Combined application of organic resources (OR) and mineral nutrient sources (MR) has been accepted as one of the appropriate ways to address soil fertility decline and it constitutes the backbone of integrated soil fertility management (ISFM). Combining OR and MR N has been shown to improve crop yields compared to the sole application of either, reduce nutrient losses through leaching, and improve N mineralization of OR. This has been mainly attributed to direct interactions between the two resources where temporary immobilization of the nutrients from MR may result in better synchrony between demand and supply of plant nutrients. While aggregate dynamics have not been looked at as a mechanism that could control nutrient cycling in agricultural systems which rely on these combinations, it is known that accumulation of C and N is related to aggregation. Aggregates physically protect SOM and form temporary nutrient pools which are released upon breakdown of aggregates. Aggregate formation and breakdown, i.e. aggregate turnover, plays an important role in the short- and long-term stabilization of C. Residue quality and mineral N have been shown to influence aggregate formation and breakdown with high quality OR resulting in faster aggregate turnover and a slower aggregate turnover with low quality OR. The objectives of this study were to determine the influence of addition of OR of varying quality, alone or in combination with MR (excluding root growth influence) on aggregate turnover, and soil C and N dynamics in the short-term.

## Materials and methods

A microplot study was carried out, at Embu Research Station ($0^o30'$ S, $37^o27'$ E; 1380 m above sea level) in the Central Highlands of Kenya. *Tithonia diversifolia* (high quality), *Calliandra calothyrsus* (medium quality) and *Zea mays* residues (low quality) were applied to soil at an equivalent C rate of 4 Mg C $ha^{-1}$ compared to no input control, alone or with 120 kg N $ha^{-1}$ as calcium ammonium nitrate. Soil had been under the same treatment in a field experiment for 4 years. No crops were grown in both the field and micro-plots. Soil samples were collected at installation of the microplots (time 0), 2, 5, 9 months after installation (time I, II and III, respectively) and separated into different aggregate fractions using the wet sieving method. Macroaggregates were further fractionated to separate the microaggregates within the macroaggregates. Total soil and the fractions were analyzed for C and N.

## Preliminary results

The addition of OR increased organic C and total N compared to the control at all sampling times **(Table 8)**. Bigger differences among treatments were observed at the second sampling time where sole *Z. mays* residues had 35% and 57% more C and N, respectively than the no input control. The application of sole *Z. mays* residues consistently resulted in higher amounts of organic C and N but it was only significantly higher than all treatments at times I and II. Although there was no overall effect of the addition of mineral N on whole soil C or N, there was a significant interaction between OR and mineral N additions at the first and second sampling times while there were no interactions at time zero and the third sampling. The addition of mineral N with *Z. mays* residues significantly reduced soil organic C at the first and second sampling times with decreases of 8.6% and 13.7%, respectively, compared to *Z. mays* alone **(Table 8)**.

The addition of OR increased the proportion of both large and small macroaggregates compared to the control, resulting in higher mean weight diameter with the addition of OR compared to the control. Consequently there was a decrease in the microaggregates and silt and clay fractions in soils where OR was added compared to the control and MR alone. The proportion of macroaggregates, especially large macroaggregates increased through time for soil treated with *C. calothyrsus* and *Z. mays* residues coupled by a decrease in the proportion of microaggregates through time. Macroaggregates were composed mostly of microaggregates while coarse POM accounted only for about 1.5% of the whole soil. Higher proportions of microaggregates, and silt and clay within macroaggregates were observed with *T. diversifolia* and *Z. mays* while *C. calothyrsus* resulted in lower proportions, which were not significantly different from the control.

The application of *Z. mays* alone resulted in the largest organic C and N in the large macroaggregates, which was significantly bigger than the control and sole applied *C. calothyrsus* **(Figure 13)**. However, the addition of *Z. mays* residues with MR resulted in a decline in C and N in this fraction compared to *Z. mays* residues applied alone **(Figure 13)**. In the microaggregates the addition of *Z. mays* residues alone resulted in the least organic C contents, lower than treatments with no OR additions. In the microaggregates within macroaggregates, the addition of *T. diversifolia* residues resulted in the greatest organic C contents at all sampling times but was not significantly different from *Z. mays*. Significant differences were however, only observed at times I and II while there were no differences at times 0 and III.

**Preliminary conclusions**

Addition of OR results in higher organic C and N concentrations and higher proportions of stable macroaggregates compared to the no input control. Organic resource quality influences soil organic C and N, aggregate turnover and aggregate C dynamics in the short-term but not in the long-term. In the short-term, application of low quality OR leads to the formation of macroaggregates with a slow turnover and stabilization of C in microaggregates and silt and clay fractions within the macroaggregates. Combined application of OR with MR did not influence soil organic C and N dynamics and aggregate dynamics for high quality OR, but significantly reduced soil C and N and induced faster aggregate turnover of *Z. mays* residues which are low quality.

**Table 8:** Total organic C and N of soil amended with organic resources of different quality applied at 4 Mg C ha$^{-1}$, alone or in combination with 120 kg N ha$^{-1}$ (120N) as mineral fertilizer at Embu in the central highlands of Kenya. Soils were sampled at installation of the experiment (Time 0), after 3, 6 and months (Time I, II and III, respectively).

| **Treatment** | **Organic C g C kg$^{-1}$ dry soil** | | | | **Organic N g N kg$^{-1}$ dry soil** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Time 0** | **Time I** | **Time II** | **Time III** | **Time 0** | **Time I** | **Time II** | **Time III** |
| Control | $24.9^{b}$ | $27.7^{c}$ | $26.7^{d}$ | $26.5^{b}$ | $2.2^{c}$ | $2.3^{c}$ | $2.1^{d}$ | $2.1^{b}$ |
| Fertilizer | $26.0^{b}$ | $26.9^{c}$ | $26.6^{d}$ | $26.8^{b}$ | $2.4^{bc}$ | $2.4^{c}$ | $2.4^{cd}$ | $2.3^{b}$ |
| *T. diversifolia* | $30.9^{a}$ | $32.3^{ab}$ | $32.6^{b}$ | $30.9^{a}$ | $2.7^{ab}$ | $2.9^{ab}$ | $2.9^{b}$ | $2.5^{ab}$ |
| *T. diversifolia* + 120N | $31.7^{a}$ | $33.4^{ab}$ | $33.4^{b}$ | $31.4^{a}$ | $2.9^{a}$ | $2.9^{ab}$ | $2.9^{b}$ | $2.6^{a}$ |
| *C. calothyrsus* | $30.5^{a}$ | $31.2^{b}$ | $32.0^{bc}$ | $29.9^{ab}$ | $2.7^{ab}$ | $2.5^{bc}$ | $2.9^{b}$ | $2.5^{ab}$ |
| *C. calothyrsus* + 120N | $30.9^{a}$ | $32.4^{ab}$ | $31.8^{c}$ | $30.7^{a}$ | $2.8^{a}$ | $2.8^{ab}$ | $2.8^{b}$ | $2.7^{a}$ |
| *Z. mays* | $31.9^{a}$ | $34.2^{a}$ | $36.0^{a}$ | $32.8^{a}$ | $2.9^{a}$ | $3.0^{a}$ | $3.3^{a}$ | $2.8^{a}$ |
| *Z. mays* + 120N | $31.5^{a}$ | $31.4^{b}$ | $31.0^{c}$ | $30.6^{a}$ | $2.8^{a}$ | $2.7^{b}$ | $2.7^{bc}$ | $2.3^{b}$ |
| | Statistical significance | | | | | | | |
| OR | * | * | | | * | * | | |
| N | Ns | Ns | | | ns | ns | | |
| OR*N | Ns | * | | | ns | ** | | |
| Time | Na | Ns | | | na | ** | | |
| OR*N*time | Na | Ns | | | na | *** | | |

Values followed by different superscript letters ($^{a\text{-}d}$) in the same column are significantly different ($p<0.05$).

***$p<0.001$, **$p<0.01$, *$p<0.05$, ns- not significant at $p<0.05$, na- not applicable.

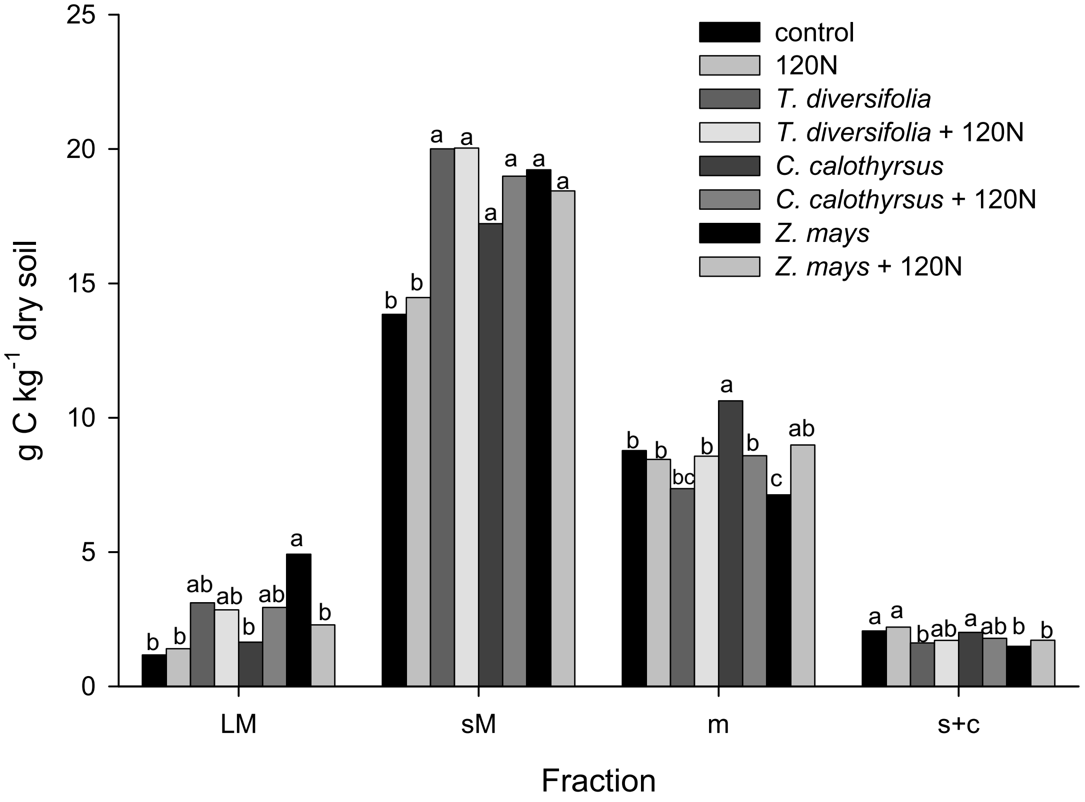

**Figure 13:** Organic C distribution among aggregate fractions following application of different quality organic resources alone or with 120 kg N $ha^{-1}$ (120N) as mineral N fertilizer in a clay soil in Embu, central Kenya of samples collected in September 2005. Bars followed by the same letter (a-b) within the same fraction are not significantly different.

## Incorporation of new nitrogen in aggregate size fractions and the short-term dynamics are influenced by organic resource quality.

**P. Chivenge[1], B, Vanlauwe[2], R. Gentile[1] and J. Six[1]**
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### Introduction

One of the major challenges of integrated soil fertility management (ISFM) in sub-Saharan Africa (SSA) is the optimal management of available organic resources (OR) and the efficient utilization of the limited mineral fertilizers (MR) for improved crop productivity and the attainment of food security. The combined application of OR and MR can improve crop yields by improving the synchrony between supply and demand of crop nutrients through direct and indirect interactions of the two sources or by protection of the OR within soil aggregates. This is however, dependent on the quality of OR which influences the balance between long-term C sequestration coupled with soil sustainability versus nutrient availability and short-term nutrient dynamics. Low quality OR may enhance soil organic matter (SOM) build-up through slower aggregate turnover, especially macroaggregates, and greater C stabilization in the macroaggregates. This study sought to understand the linkage between OR quality and soil organic matter (SOM) stabilization within aggregate fractions and how the addition of MR would alter the dynamics. It was hypothesized that high quality OR would induce a faster macroaggregate turnover associated with less SOM stabilization while the addition of MR would also accelerate the turnover of added SOM.

### Materials and methods

A microplot experiment was conducted in Embu, central Kenya where $^{13}C^{14}N$ or $^{13}C^{15}N$ labeled *Tithonia diversifolia* (high quality), *Calliandra calothyrsus* (medium quality) and *Zea mays* residues (low quality) were applied to soil at an equivalent C rate of 4 Mg C ha$^{-1}$ compared to no input control, alone or with $^{14}N$ or $^{15}N$ 120 kg N ha$^{-1}$ as calcium ammonium nitrate. Soil had been under the same treatment (but using non labeled OR or MR) in a field experiment for 4 years. Soil samples were collected at installation of the microplots (time 0), 2, 5, 9 months after installation (time I, II and III, respectively) and separated into different aggregate fractions using the wet sieving method. Macroaggregates were further fractionated to separate the microaggregates within the macroaggregates. Total soil and the fractions were analyzed for elemental and isotopic C and N.

### Preliminary results

The addition of OR increased total N compared to the control at all the sampling times but bigger differences among treatments were observed at the second sampling time where sole *Z. mays* residues had 57% more N than the no input control. Although higher concentrations of total N were observed under the sole *Z. mays* treatment, the incorporation of new N was slower than the other OR **(Figure 14)**. There was a decline in the incorporation of new N in the soil through time with similar new N values under the 3 OR by the ninth month after installation of the experiment. For most fractions bigger differences in new N among OR quality classes were observed 2 months after residue incorporation.

*Tithonia diversifolia* applied alone had about 82% higher concentrations of new N in the small macroaggregates than the other OR at time I and this trend persisted in the microaggregates within macroaggregates which had 0.4 and 0.5 times more N than *C. calothyrsus* and *Z. mays*, respectively.

There was a general increase in the incorporation of new N in aggregate fractions over time for all OR when $^{15}$MR was added with $^{14}$OR. In comparisons across OR in the small macroaggregates differences were only observed at the second sampling time where *C. calothrysus* had more new N which was double that in *Z. mays* treatment while there were no differences between *T. diversifolia* and *Z. mays* residues **(Figure 15)**. In the small macroaggregates of *C. calothyrsus*, differences among treatments within the OR were observed at times I and II where the $^{15}$OR applied with $^{14}$MR had the highest proportions of new N while the treatment with $^{14}$OR and $^{15}$MR had the lowest proportions of new N **(Figure 15)**. By time III however, there were no differences between the two treatments, which were similar to sole MR but had greater proportions of new N than the sole OR treatment. In comparison, sole MR had greater proportions of new N in the small aggregates at time III than all the treatments of *Z. mays* **(Figure 15)**.

Similar to small macroaggregates, the addition of $^{15}$OR with $^{14}$MR resulted in *C. calothyrsus* having about 6 and 3 times more new N than *T. diversifolia* and *Z. mays*, respectively in the cPOM at times I and II. At time III there were no significant differences between *C. calothyrsus* and *Z. mays*, both which had greater proportions of new N than *T. diversifolia* and sole MR. In microaggregates within macroaggregates *T. diversifolia* had greater proportions of new N while maize had the least which was consistent at all the sampling times. At time III sole MR had higher proportions of new N in the microaggregates within macroaggregates than all the *Z. mays* treatments. These trends were similar to those observed in the microaggregates and silt and clay within macroaggregates. Sole MR incorporated greater proportions of new N in the silt and clay fractions mostly at times II and III than all the other treatments.

**Preliminary conclusions**

The addition of low quality OR, such as *Z. mays* residues, results in the stabilization and accumulation of total N in soil and macroaggregates which have a slow turnover rate. In contrast, there is fast decomposition of OR coupled with faster aggregate turnover under high quality OR such as *T. diversifolia* with stabilization of added OR in the stable aggregate fractions such as microaggregates. The addition of MR in combination with OR does not enhance decomposition nor influence new N dynamics under readily available high quality OR whereas under low quality OR, it results in an increase in OR decomposition coupled with increased aggregate turnover and faster incorporation of new N. Thus there is no added benefit in applying high quality OR in combination with MR, but may lead to nutrient losses.

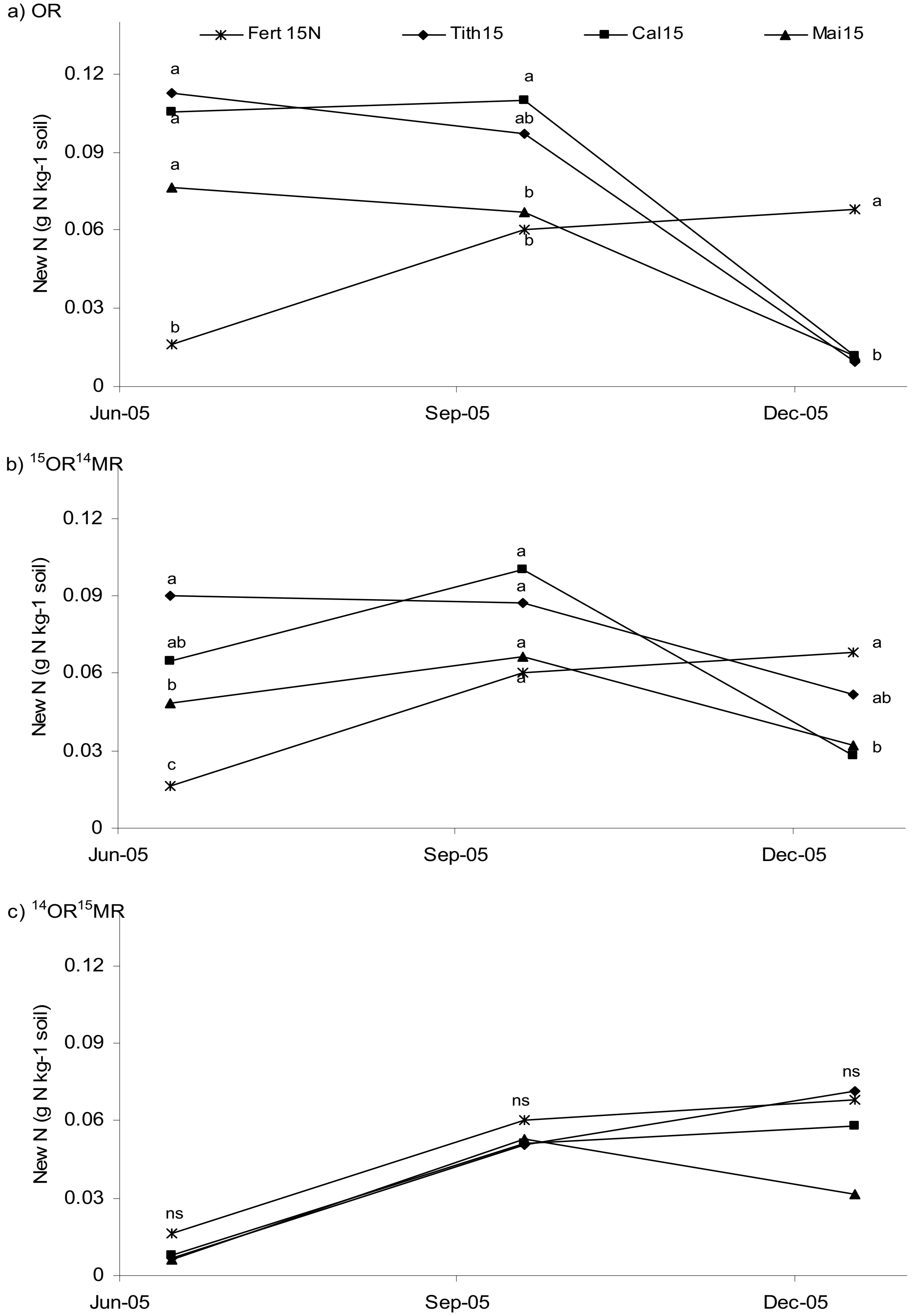

**Figure 14:** New N ($^{15}N$) dynamics of whole soil amended with $^{14}N$ or $^{15}N$ labeled organic resources of varying quality applied at an equivalent rate of 4 Mg C ha$^{-1}$ alone or in combination with $^{14}N$ or $^{15}N$ mineral N on a clay soil at Embu in the central highlands of Kenya. Soil was sampled 2, 5 and 9 months after residue incorporation.

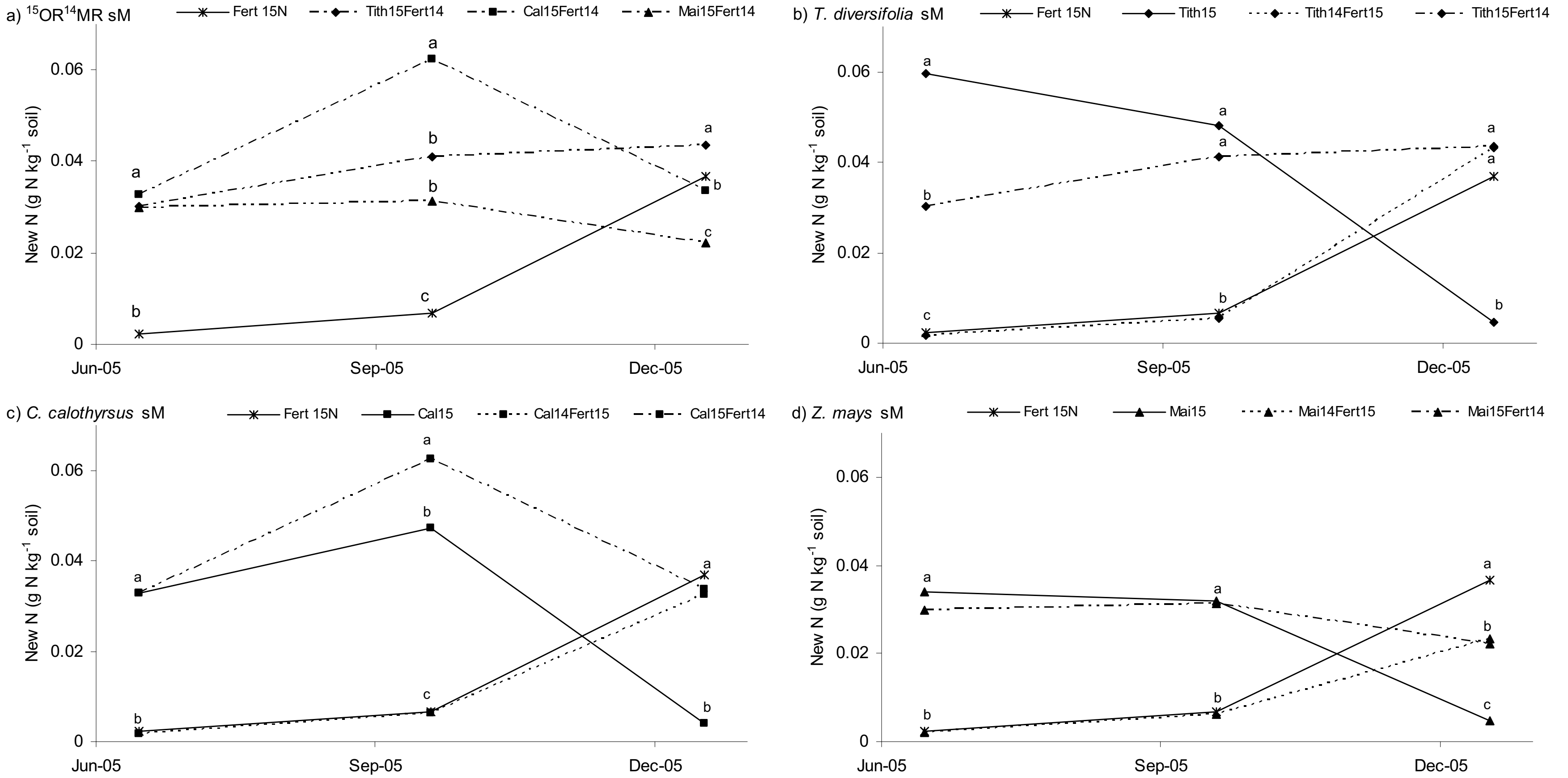

**Figure 15:** New N ($^{15}$N) dynamics of small macroaggregates (sM amended with a) different quality organic resources applied as $^{15}$OR$^{14}$MR, b) *T. diversifolia* ($^{15}$OR, $^{15}$OR$^{14}$MR, $^{14}$OR$^{15}$MR, $^{15}$MR), c) *C. calothyrsus* ($^{15}$OR, $^{15}$OR$^{14}$MR, $^{14}$OR$^{15}$MR, $^{15}$MR), and d) *Z. mays* ($^{15}$OR, $^{15}$OR$^{14}$MR, $^{14}$OR$^{15}$MR, $^{15}$MR). Organic resources were applied at an equivalent rate of 4 Mg C ha$^{-1}$ on a clay soil from Embu in the central highlands of Kenya.

## Short-term N dynamics as affected by organic resource quality and fertilizer application in Central Kenya.

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### Introduction

The focus of this project is on identifying the ecological principles governing rates of N cycling in agroecosystems, with the ultimate aim of contributing to the development of more efficient management practices. The Integrated Soil Fertility Management paradigm recognizes the benefits of combined use of organic and mineral inputs. However, these benefits may be regulated by residue quality, which is a controlling factor in the rate of nutrient release from organic fertilizers. Our previous research has shown that residue quality has no impact on long-term soil C and N stabilization. However, we also found that input management influenced short-term N dynamics in a controlled incubation study. Therefore, we examined the effect of organic residue quality and combining organic with mineral N fertilizers on short-term N cycling under field conditions. Our objectives were to determine the effect of input quality on short-term N cycling and maize uptake. We hypothesized that combining low quality organic and mineral N inputs will reduce system losses of N by synchronizing gross mineralization rates with plant N uptake.

### Materials and Methods

The SOM research trial is located at Embu, Kenya and was initiated in 2002 to examine the long-term effects of application of different quality organic residues and N mineral fertilizer. The experiment has a split plot design with the organic resource input as the main plot and fertilizer application as the subplot. For the present study, we sampled from organic matter treatments consisting of a control plot with no residue, high quality *Tithonia diversifolia* residue (3% N), and low quality maize stover residue (0.7% N) with residues applied at a rate of 4 Mg C $ha^{-1}$. Subplots receive either 0 or 120 kg N $ha^{-1}$ as calcium ammonium nitrate in a split-application. All inputs are incorporated into the soil to a depth of 15 cm. Maize is grown in the cropped plots each growing season. During the long rains of 2007 (April to September) we monitored soil available N and plant growth during the 11th growing season of the trial. Soil was sampled to 60 cm in increments of 0-15, 15-30, and 30-60 cm and analyzed for extractable mineral N at crop emergence, 1st fertilizer application, 2nd fertilizer application, flowering, and harvest. Plant biomass samples were also collected at time of soil sampling and measured for dry weight as well as N content. Additionally, soil from 0-15 cm at each sampling was air-dried and further used to measure potential gross mineralization and nitrification rates using $^{15}N$ pool dilution incubation techniques.

### Preliminary results

The different input treatments altered available N in the 0-60 cm soil profile over the coarse of the growing season **(Figure 16)**. The Tithonia residue application showed early season release of N to 30 d after planting as compared to the control and stover treatments. The addition of mineral N fertilizer at 30 and 49 d after planting increased available N in all the 120 kg N $ha^{-1}$ treatments, though the stover treatment maintained lower N levels than the control and Tithonia treatments with mineral N additions. Corresponding with higher levels of available N during the growing season, the treatments with 120 kg N $ha^{-1}$ additions also produced more maize biomass **(Figure 17)**.

The stover with 120 kg N ha$^{-1}$ treatment produced the most biomass, while the stover with 0 kg N ha$^{-1}$ produced the lowest amount of biomass. Results on the N contents of the maize biomass, and gross mineralization and nitrification rates are still pending. With this data we will construct N budgets for each treatment link observed changes in the available N pool with N transformation rates.

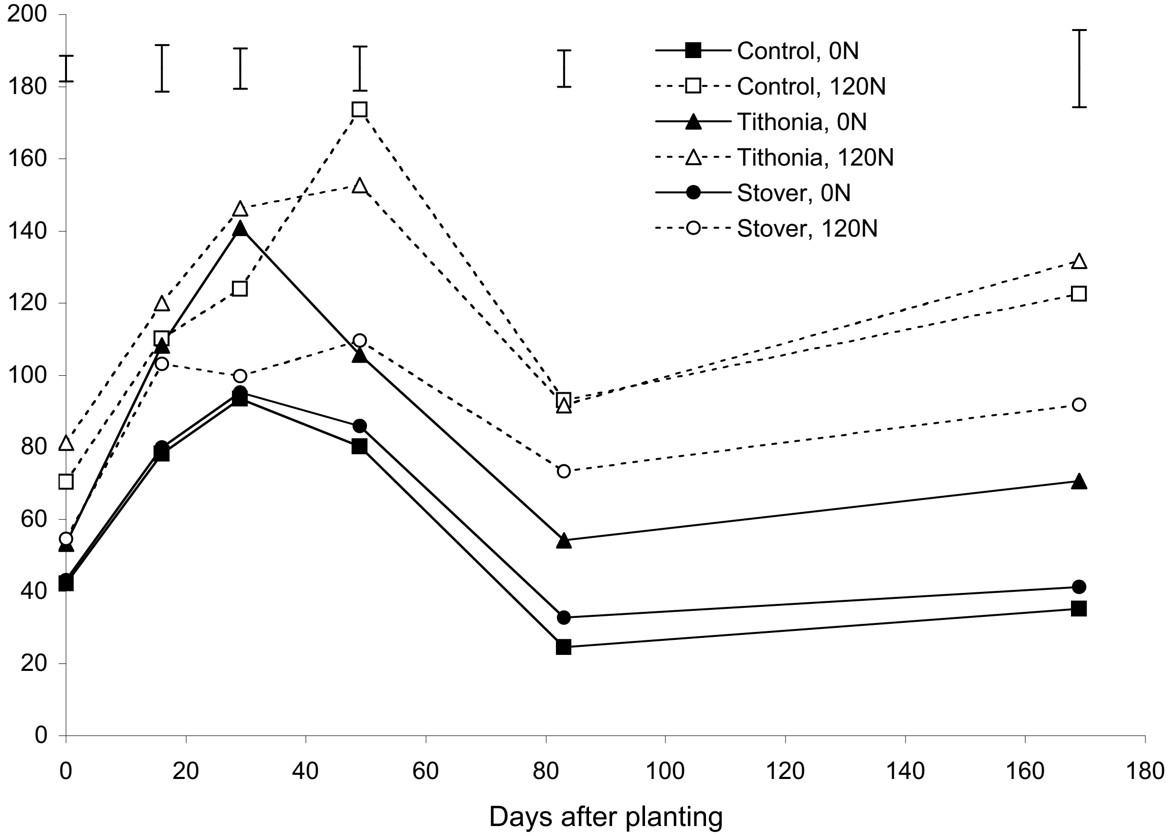

**Figure 16:** Soil extractable mineral N in the 0-60 cm profile during a maize growing season under different residue and mineral fertilizer inputs. Bars represent one standard error.

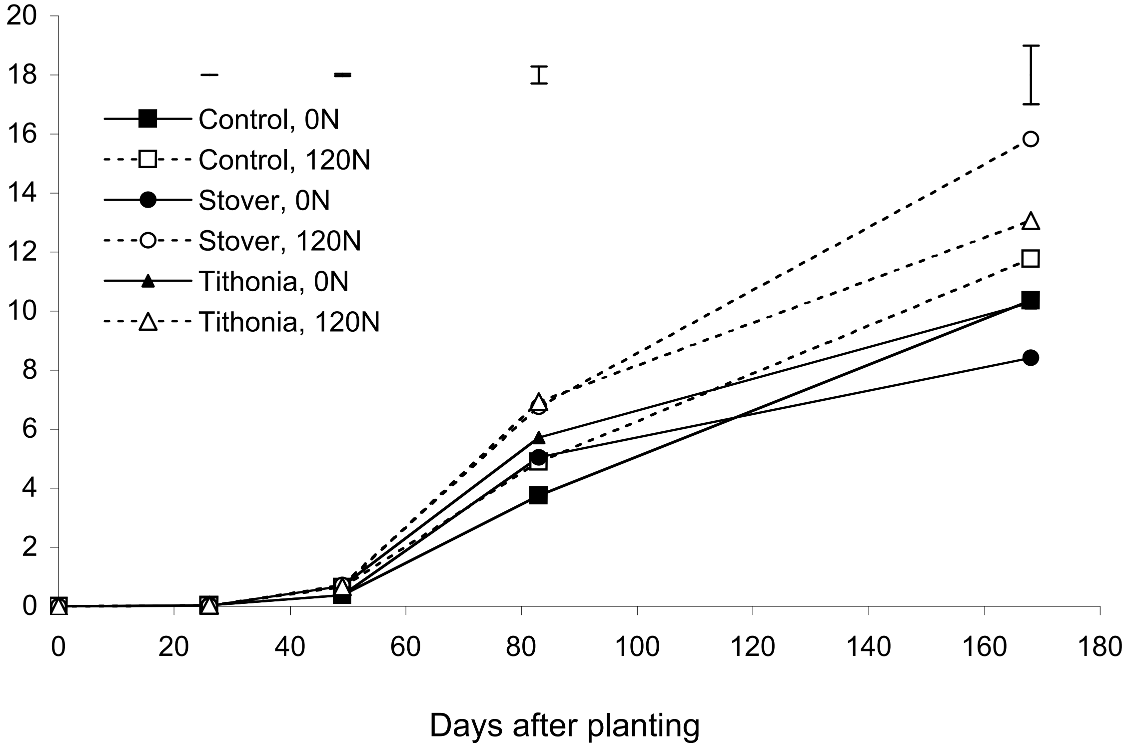

**Figure 17:** Total maize biomass during a growing season under different residue and mineral fertilizer inputs. Bars represent one standard error.

### Preliminary conclusions

The application of high quality organic residue showed early season release of available N. However, this early N under high quality residues did not translate into greater biomass production and may indicate higher N losses from agroecosystem. Conversely, the application of low quality organic residue combined with mineral N fertilizer showed lower levels of available N throughout the season yet produced an equivalent amount of biomass as the other residue input treatments. This provides early support for our hypothesis that combining low quality residue with mineral fertilizer leads to more efficient N cycling.

## Genetic diversity of Rhizobia nodulating promiscuous soybean varieties in Kenya: V. Wasike[1], D. Lesueur[2], B. Vanlauwe[2].

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### Introduction

Current interest in soybean in Kenya is due to its potential role as food, feed, soil fertility improvement. and income generation However, this potential cannot be fully exploited since current varieties are low yielding and have low soil improving characteristics unless inoculated with rhizobium bacteria to enhance their nodulation and nitrogen fixing ability. Promiscous varieties are able to nodulate with rhizobia inherent in Kenya soils Yet compatible populations of specific *Bradyrhizobium* species necessary for nodulation for nodulation of soyabean are seldom available where the crop has not been grown previously. *Bradyrhizobium japonicum* inoculation is therefore required in order to achieve adequate and effective nodulation of soyabean when the crop is first introduced to many tropical soils that may contain high cowpea rhizobial populations. Promiscous soyabean or TGx varieties (crosses between non promiscuous North American soybean genotypes and promiscuous Asian soybean genotypes) were bred by IITA to nodulate with indigenous rhizobia and also provide a substantial amount of seed yield. The presence in sufficient populations of effective indigenous soil rhizobia can facilitate TGx. varieties to derive N through BNF and to determine whether or not they will respond to added rhizobia or N fertilizer. Indigenous rhizobia associated with leguminous crops are diverse and usually exhibit this diversity in their genetic constitution as well as competiveness and effectivity with and between hosts. Obtaining knowledge on the genetic diversity of indigenous bradyrhizobial populations in Kenya soils will be valuable in developing strategies to improve biological nitrogen fixation and thus increase soyabean yields at low cost. The objectives of the study were (1) to assess whether seven introduced promiscuous soybean varieties nodulate with indigenous rhizobia in three sites at the Coastal lowlands (Mtwapa, Chonyi and Msabaha) and two sites in the highlands (Bungoma and Mitunguu) in Kenya, (2) to assess the genetic diversity of these indigenous rhizobia, and (3) to determine the genetic relatedness of the indigenous rhizobia with type and other strains.

## Materials and Methods

Field experimental sites were selected in two sites in different agro-ecological zones in the highlands (humid [Bungoma (LM$_1$) and semi-humid [Meru (LM$_3$) and Coast lowlands (Msabaha (CL$_1$), Mtwapa (CL$_1$) and Chonyi (CL$_2$). These sites also represent the major and potential soyabean growing agro-ecological zones in Kenya. At the coastal sites, plots received an equivalent of 50 kg DAP fertilizer per hectare and were arranged in randomized block design replicated three times at each site. In the highland sites, TGx. varieties were planted in a strip plot design with varieties allocated at the main while management levels at the sub-plot level. Main plot sizes were 2.5 m x 7.2m while sub-plot sizes were 2.5m x 1.8m consisting 4 rows of 2.5 metres long and 0.45 metres wide. The variety Nyala, a specific variety bred in Zimbabwe with an American soybean genetic background, was used as a non nodulating control while TGx genotypes () were used as test varieties. These were TGx 1871-12E, TGx 1895-33F, TGx1895-49F, TGx 1889-12F, TGx 1893-10F, TGx 1740-2F, TGx 1448-2E were used as test varieties. Management level combinations of; control (none), + P (40kg/ha), + lime (1t/ha), + N(90kgN /ha, split applied) + lime + P (to establish the need for inoculation) were applied at sub-plot level. The mineral input sources (TSP, lime and Urea) were applied at the sub-plot level. All inputs applied at planting were broadcasted and incorporated before planting. At top dressing the urea was banded and incorporated near the soybean lines.

After application of the fertilizer, soybean was planted in rows, 45 cm apart and drilled and later thinned to 5 cm distance between plants. Nodule sampling and storage was done as described by Weaver and Graham (1994), DNA extraction using a method described by Krasova-Wade *et al.,* (2003) while soil physical and chemical characteristics were analyzed using a method described by Page *et al* (1982) while genetic diversity was assayed using the Polymerase Chain Reaction-Restriction Fragment Length Polymorphism (PCR-RFLP) of the 16S-23S rDNA intergenic spacer region as described by Krasova-Wade *et al.,* (2003 with modifications. Phyllogeny of the isolates was achieved by analysis of the 16S rRNA gene and a phyllogentic tree constructed with PHYLIP package and bootstrap analysis performed.

## Preliminary Results

PCR amplification of DNA fragments from rhizobia obtained from 289 nodules from highland sites and 46 nodules from coastal sites and one reference strain (USDA 110) resulted in single IGS PCR products sizes ranging from 930-1100bse pairs. Digestion with restriction enzymes Msp 1 produced 18 and 8 different RFLP patterns in the highland and coastal sites respectively. In the highland sites, IGS groups I, III, II, IV and VI were the most predominant and constituted 43.4%, 24.2%, 8.4% 7.7% and 7.3%, respectively of all the analyzed nodules while IGS groups VII, IX, X, XI, XII, XIV, XVI, XVII, XVIII constituted less than 1%. The IGS groups were however, not specific / unique to any site, variety or treatment. In the coastal sites, IGS groups A, B, C and D were the most predominant and constituted 34.8, 21.7%, 13.0%, and 10.9% respectively of all the analyzed nodules while IGS groups F, G H and I constituted 19.3%. In these coastal sites, some IGS groups were specific to site and variety. Alignments of partial 16S rDNA gene sequences of the isolated strains with related I6S rRNA sequences in GenBank database revealed that B*radyrhizobium japonicum* and *B. ekanii* related strains were the most predominant and accounted for 37.9% and 41.4% respectively while *B. liaoningense* and *Bradyrhizobium spp*. accounted for 17.2% and 3.5 % respectively of all nodules analyzed from highland sites. In Coastal sites, 41.7%, 33.3%, 8.3 % and 16.7% of all the strains were closely related to *B. japonicum*, *B. elkanii*, *B. yuanmigense* and *Bradyrhizobium spp* respectively **(Table 9)**.

**Table 12:** BLAST output results of the partial 16S rDNA gene sequences from highland sites and related strains from GenBank.

| Isolate ID. | Site | Variety | Treatment | Sequence length | Accession No. | Description of closely related genus Affiliation |
|---|---|---|---|---|---|---|
| TSBF-531 | Mitunguu | SB 9 | P + lime | 810 | EU010398 | Bradyrhizobium japonicum strain CCBAU 15618 |
| TSBF-523 | Mitunguu | SB 9 | P | 804 | EU010398 | Bradyrhizobium japonicum strain CCBAU 15618 |
| TSBF-345 | Mitunguu | SB 15 | P | 813 | EU010398 | Bradyrhizobium japonicum strain CCBAU 15618 |
| TSBF-441 | Mitunguu | SB 20 | P + Lime | 782 | AF239843 | Bradyrhizobium japonicum strain PRY 40 |
| TSBF-534 | Mitunguu | SB 9 | P + Lime | 814 | EU010398 | Bradyrhizobium japonicum strain 15618 |
| TSBF-331 | Bungoma | SB 15 | Control | 811 | EU010398 | Bradyrhizobium japonicum strain 15618 |
| TSBF-336 | Mitunguu | SB 15 | Control | 797 | EU010398 | Bradyrhizobium japonicum strain 15618 |
| TSBF-341 | Bungoma | SB 15 | P | 795 | EU170557<br>AM748972(MS 867) | Bradyrhizobium liaoningense strain CCBAU 65008<br>Bradyrhizobium sp. SjCL5 |
| TSBF-333 | Mitunguu | SB 15 | Control | 802 | EU170557<br>AY624129(MS 996) | Bradyrhizobium liaoningense strain CCBAU 65008<br>Bradyrhizobium sp PAC 41 |
| TSBF-131 | Bungoma | SB 20 | P | 801 | EU170557<br>AY624129(MS 680) | Bradyrhizobium liaoningense strain CCBAU 65008<br>Bradyrhizobium species PAC 41 |
| TSBF-381 | Mitunguu | SB 17 | P+ lime | 808 | EF549400 | Bradyrhizobium elkanii strain CCBAU 83502 |
| TSBF-402 | Mitunguu | SB 19 | P | 815 | AF293380 | Bradyrhizobium elkanii strain USDA 90 |

| | | | | | | |
|---|---|---|---|---|---|---|
| TSBF-344 | Mitunguu | SB 15 | P | 812 | EF549397<br>U35000.3(MS 680) | Bradyrhizobium elkanii strain CCBAU 83387<br>Bradyrhizobium elkanii gene |
| TSBF-444 | Bungoma | SB 20 | P+ lime | 790 | EF549397<br>U35000.3(MS 1125) | Bradyrhizobium elkanii strain CCBAU 83387<br>Bradyrhizobium elkanii gene |
| TSBF-404 | Mitunguu | SB 19 | P | 766 | AY972228<br>AY904788(blastn) | Bradyrhizobium elkanii strain SEMIA 6425 |
| TSBF-442 | Bungoma | SB 20 | P + lime | 790 | EF549397<br>AF362942(MS 870) | Bradyrhizobium elkanii strain CCBAU 83387<br>Bradyrhizobium elkanii gene |
| TSBF-101 | Bungoma | SB 19 | P | 757 | EF549397 | Bradyrhizobium elkanii strain CCBAU 83502 |
| TSBF-260A | Bungoma | SB 9 | P | 790 | EF549397 | Bradyrhizobium elkanii strain CCBAU 83387 |
| TSBF-336A | Mitunguu | SB15 | Control | 772 | EF549397<br>AF510608(MS 872) | Bradyrhizobium elkanii strain CCBAU 83387<br>Bradyrhizobium sp vqs-3 |
| TSBF-504 | Mitunguu | SB 8 | P + Lime | 774 | EF549397 | Bradyrhizobium elkanii strain CCBAU 83387 |
| TSBF-216 | Bungoma | SB 8 | Control | 810 | AF530465 | Bradyrhizobium japonicum isolate JZ 1 |
| TSBF-161 | Bungoma | SB 4 | P | 815 | AF293380 | Bradyrhizobium elkanii USDA 90 |
| TSBF-488 | Mitunguu | SB 8 | Control | 850 | EU 170557<br>AY624129(MS 581) | Bradyrhizobium liaonigense strain strain CCBAU 65008<br>Bradyrhizobium sp. PAC 41 |
| TSBF-101 | Bungoma | SB 19 | P | 802 | EU170557<br>AY624129(MS 699) | Bradyrhizobium sp PAC 4 |

**Table 10:** BLAST output results of the partial 16S rDNA gene sequences from Coastal sites and related strains from GenBank.

| Isolate | Sequence length (bp) | Species affiliation* | IGS group Msp 1 | % Similarity | Accession number |
|---|---|---|---|---|---|
| TSBF-607 | 810 | *Bradyrhizobium japonicum* isolate WC4 | A | 86 | AF530466 |
| TSBF-639 | 780 | *Bradyrhizobium* species CCBAU 35186 | B | 76 | DQ26711 |
| TSBF-640 (EU360580) | 788 | *Bradyrhizobium* species PAC 41 | B | 80 | AY624129 |
| TSBF-666 (EU360581) | 794 | *Bradyrhizobium elkanii* strain BR3277 | C | 95 | AY649431 |
| TSBF-694 (EU360582) | 806 | *Bradyrhizobium elkanii* strain BR3277 | C | 94 | AY649431 |
| TSBF-627 (EU360583) | 815 | *Bradyrhizobium yuanmingense* strain CCBAU 33230 | D | 88 | EU170554 |
| TSBF-717 (EU360584) | 813 | *Bradyrhizobium elkanii* strain USDA 31 | E | 83 | AF208512 |
| TSBF-695 (EU360585) | 809 | *Bradyrhizobium japonicum* strain CCBAU 53152 | H | 82 | EF394144 |
| TSBF-734 (EU360586) | 815 | *Bradyrhizobium japonicum* isolate WC4 | F | 85 | AF530466 |
| TSBF-718 (EU360587) | 749 | *Bradyrhizobium japonicum* isolate WC4 | G | 78 | AF530466 |
| TSBF-701 (EU360588) | 774 | *Bradyrhizobium elkanii* strain CCBAU 83387 | E | 94 | EF549397 |
| TSBF-C (EU360589) (CONTROL) | 760 | *Bradyrhizobium japonicum* USDA 110 | - | 67 | BA000040 |

*Species affiliation based on homology using partial 16S rRNA gene sequence analysis

## Preliminary conclusions

Indigenous rhizobia nodulating promiscuous soybean varieties in Kenya soils are grouped in *Bradyrhizobium* genera. The *Bradyrhizobia* were closely related to *Bradyrhizobium japonicum, Bradyrhizobium elkanii, Bradyrhizobium liaoningense Bradyrhizobium yuaningmingense* and *Bradyrhizobium spp*. Some isolates were specific to specific areas while others were not: (i) *Bradyrhizobium yuaningmingense* related isolates were only isolated from nodules of promiscuous soybean varieties grown at the lowland/Kenyan coast region and (ii) *Bradyrhizobium liaoningense* related isolates were only isolated from nodules of promiscuous soybean varieties grown in highland /upcountry *sites* (Bungoma and Mitunguu-Meru*)*. *Bradyrhizobium spp* related isolates were found in both areas (Coast and up country) and is a diverse group that could represent *Bradyrhizobium spp* (TGx) which constituted 3.5 % respectively of all strains identified upcountry and 16.77% of all strains in coastal sites.

## Survey of the biodiversity of termite functional group across the sub-humid to semi-arid agro-ecological zones of East and West Africa under low input cropping systems.

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### Introduction

The importance of termites in the decomposition of plant matter in natural and agricultural ecosystems is well documented. Termites also play a significant role in soil nutrient availability and cycling through interactions with other soil organisms e.g. bacteria and fungi most of whom they avail food to. Thus, they contribute positively to soil ecological processes in these systems. Mound-building species form stable microaggregates that physically protect occluded organic matter against rapid decomposition and reduce soil erosion and crust formation. Despite their overall value in soil ecology and in the maintenance of the structure and function of the belowground ecosystems, macrofauna (e.g. termite) importance is often overlooked. Equally little is known about the spatial distribution of different taxa of termites in agricultural soils across climatic regions and soil types of East and West Africa and of the management practices that stimulate their activity. This study therefore aimed at: 1) quantifying the assemblage of termite taxa or functional group across a transect of the sub-humid to semi-arid agro-ecological zones of East and West Africa, 2) evaluate the environmental factors that influence distribution patterns observed in (1) above.

### Materials and Methods

The study was conducted in 12 long-term field trials across the sub-humid to semi-arid agro-ecological zones of East (Embu, Kabete, Impala and Nyabeda: Kenya and Lilongwe: Malawi) and West (Tamale: Ghana, Ibadan: Nigeria, Farakoba and Saria I, II and III: Burkina Faso, Sadore: Niger) Africa. These on-going long-term trials were established in the past one to four decades and aimed at testing different management options (e.g. organic resource inputs, mineral N use, crop rotation and tillage). Two different sampling methods were employed for termite assessments. In a first monolith sampling, macrofauna (termites) were sampled according to the standard TSBF method using randomly taken monolith units of size 25 cm 25 cm x 30 cm. Treatments selected included those with high soil C, low C and undisturbed reference sites (either fallow plots or close by forest or shrubland). One soil monolith (25 x 25 x 30 cm) sample per plot (n=3) were taken for termite sampling, 8 weeks after planting. Collected termites were preserved in 75% alcohol before being transported in sealed vials to the laboratory for processing (taxonomic analysis, enumeration and biomass determination), at the Department of Entomology of the National Museums of Kenya, Nairobi. Unidentified samples were preserved and worked on later at the Natural History Museums in London (Britain). The transect sampling for termites was done alongside monolith sampling protocols. In each sampling plot a 20 x 2 m transect (or 5 x 2 m sections) were randomly laid. Each transect or section was sampled sequentially and the following microhabitats which are common sites for termites searched in details: surface soil to 5 cm depth; the soil between large buttress roots if any; the inside of branches and twigs; the soil within and beneath very rotten logs or pieces of dead woods; all subterranean nests, mounds, carton sheeting and runways on vegetation, and arboreal nests up to a height of 2 m above ground level. Termites were again collected and preserved in 75% alcohol. These were transported in sealed glass and plastic bottles to the laboratory and handled in the same way as was done for the monolith samples.

### Preliminary results

A total of 17 genera/species were sampled across East and Western Africa cropping systems. However, the distribution of termite species across sites was highly variable ranging between 1 and 5 across the land management systems (high C, low C and the fallow) **(Table 11)**. Some sites recorded higher species diversity but these differed across the land management systems. For instance in Farakoba, high C system had 5 species recorded while the low C system had only one species observed. High C systems in some most of the sites recorded between 1 and 3 **(Table 11)**. Some low C systems such as those of Ibadan and Saria I had no species recorded, while the others with exception of Sadore had a few species (1-2) observed. These could be attributed to low availability of food resources in such systems. Fallow systems equally were variable with some sites recording between 3 and 4 species **(Table 11)**.

**Table 11:** Termite diversity across East and West Africa cropping systems

| | **Treatments** | | | |
|---|---|---|---|---|
| **Site** | **High C** | **Low C** | **Fallow** | **Scavenged samples** |
| **Farakoba Burkina Faso** | *Microtermes sp.*<br>*Odontotermes sp.*<br>*Ancistrotermes cavithorax.*<br>*Nasutitermes sp.*<br>*Microcerotermes parvulus* | *Pseudacanthotermes sp.* | *Nasutitermes sp.*<br>*Microtermes sp.* | |
| **Ibadan, Nigeria** | *Microtermes sp.*<br>*Ancistrotermes cavithorax* | - | *Microtermes sp.*<br>*Ancistrotermes cavithorax,*<br>*Termes baculi,*<br>*Pseudacanthotermes sp.* | |
| **Sadore, Niger** | *Microtermes sp.*<br>*Psammotermes allocerus* | *Microtermes sp.*<br>*Psammotermes allocerus,*<br>*Odontotermes sp.*<br>*Microcerotermes parvulus.* | *Psammotermes allocerus,*<br>*Microtermes sp.* | |
| **Saria I Burkina Faso** | *Odontotermes magdalenae* | *Odontotermes magdalenae* | *Amitermes stephensoni.*<br>*Nasutitermes sp.*<br>*Macrotermes subhyalinus*<br>*Microcerotermes parvulus.* | |
| **Saria II Burkina Faso** | *Microtermes sp.*<br>*Nasutitermes sp.* | *Odontotermes magdalenae* | *Nasutitermes sp.* | *Captotermes intermedias* |
| **Saria III Burkina Faso** | *Odontotermes magdalenae* | - | *Nasutitermes sp.*<br>*Microtermes sp.*<br>*Macrotermes subhyalinus.* | |
| **Tamale, Ghana** | *Microtermes sp.*<br>*Nasutitermes sp.* | *Microtermes sp.*<br>*Amitermes stephensoni*<br>*Odontotermes sp.* | *Ancistrotermes cavithorax*<br>*Nasutitermes sp.*<br>*Microtermes sp.* | |

|  |  |  |  |  |
|---|---|---|---|---|
| **Chitala, Malawi** | *Macrotermes nr. Vitrialatus,*<br>*Microtermes sp.*<br>*Microcerotermes parvulus.* | *Odontotermes sp.*<br>*Microtermes sp.* | *Macrotermes subhyalinus.*<br>*Macrotermitinae ?*<br>*Macrotermes nr. Vitrialatus*<br>*Schedorhinotermes lamanianus Nasutitermes sp.* | *Odontotermes sp.* |
| **Embu, Kenya** | *Microtermes sp.*<br>*Odontotermes sp.* | *Pseudacanthotermes sp.*<br>*Odontotermes sp.* | *Odontotermes sp.* |  |
| **Impala, Kenya** | *Pseudacanthotermes sp.* | *Pseudacanthotermes sp.*<br>*Microtermes sp.* | *Pseudacanthotermes sp.*<br>*Tubeculitermes sp* |  |
| **Nyabeda, Kenya** | *Pseudacanthotermes sp.* | *Pseudacanthotermes sp.*<br>*Microtermes sp.* | *Pseudacanthotermes, sp.*<br>*Tubeculitermes sp* |  |
| **Kabete, Kenya** | *Microtermes sp.*<br>*Odontotermes sp.* | *Pseudacanthotermes sp.*<br>*Odontotermes sp.* | *Odontotermes sp.* |  |

**Table 12:** Termite Trophic/Functional group

| Genus/Species | Group | Feeding group | Trophic/ Functional group |
|---|---|---|---|
| *Captotermes intermedias* | Rhinotermitidae/Rhinotermitinae | I | WLG |
| *Psammotermes allocerus* | Rhinotermitidae/Psammotermitinae | I | WLSD |
| *Schedorhinotermes lamanianus* | Rhinotermitidae/Rhinotermitinae | I | WLG |
| *Amitermes hastatus* | Termitidae/Termitinae/*Amitermes* | II | WLSD |
| *Amitermes stephensoni* | Termitidae/Termitinae/*Amitermes* | II | WLSD |
| *Microcerotermes parvulus* | Termitidae/Termitinae | II | WLG |
| *Ancistrotermes cavithorax* | Termitidae/Macrotermitinae | II | WLG |
| *Macrotermes nr. vitrialatus* | Termitidae/Macrotermitinae | II | FWLG |
| *Macrotermes subhyalinus* | Termitidae/Macrotermitinae | II | FWLG |
| *Macrotermes* sp | Termitidae/Macrotermitinae | II | FWLG |
| *Microtermes* sp | Termitidae/Macrotermitinae | II | FWLG |
| *Nasutitermes* sp | Termitidae/Nasutitermitinae | II | WLG |
| *Odontotermes magdalenae* | Termitidae/Macrotermitinae | II | FWLG |
| *Odontotermes* sp | Termitidae/Macrotermitinae | II | FWLG |
| *Pseudocanthotermes* sp | Termitidae/Macrotermitinae | II | WLSD |
| *Termes baculi* | Termitinae/*Termes* | III | WS |
| *Tubeculitermes* sp | Termitinae/*Cubitermes* | IV | S |

**Key:** W=wood; L=litter; S=soil; D=Dung/manure; F=fungus grower; G=grass

In terms of feeding/trophic levels, all the four different categories of termites groups were represented. The assemblages were dominated by general feeders (Group II) in the subfamily Macrotermitinae followed by group I that are equally generalists **(Table 12)**. However, specialized soil feeders (Group III and IV) were least represented across the sites.

## Conclusions

The study demonstrates that quantitative changes in diversity and density of termites occur when fallow, cultivated or arable lands are subjected to varying levels of intensification or management regimes. These changes appear to be associated with management practices such as continuous cultivation, monocropping, use of agrochemicals, and consequent destruction of nesting habitats, modification of soil microclimate within these habitats and removal of substrate and low diversity and availability of food sources for the associated macrofauna groups.

➢ ***Functional interpretations of belowground biodiversity made and linked to ISFM and IPM***

**Work in progress**

During 2007, BGBD management trials were established in all the seven countries that participate in the CSM-BGBD project. These trials look at direct (inoculation) and indirect methods for management of soil biodiversity. The indirect methods vary from improved soil organic matter management, to crop rotations to minimum tillage and improving above ground biodiversity in tree based systems. All these trials will look into the functional l aspect of the soil ecosystem associated with soil organisms. First results from these trials are not expected until 2009.

➢ ***Crop nutrient requirement, congruence of nutrient demand and nutrient supply and impacts on nutritional quality of food products understood.***

**Work in progress**

### Options for soil fertility amendment on the Walungu axis in Sud-Kivu.

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The region around in Walungu (Sud-Kivu, DRC) is ill-reputed for its acid and unfertile soils. During the baseline and characterisation studies of the CIALCA / TSBF-CIAT project, farmers expressed low soil fertility as one of the major constraints for crop production. Farmers are limited in their options for soil fertility restoration. Due to the limited cattle numbers, use of farm yard manure (FYM) is scarce, and chemical fertilizer is absent in the region. In addition, preliminary studies and observations in farmers' fields suggested potential micronutrient deficiencies. A set of exploratory trials ("FER-1") was installed with 6 farmer associations in the two action sites to investigate the potential of increasing crop yields using FYM (5 t DM ha$^{-1}$), NPK (20 kg P ha$^{-1}$), mavuno fertilizer (NPK enriched with micronutrients, 20 kg P ha$^{-1}$), lime (4 t ha$^{-1}$), and combinations of these resources. Application of *Tithonia* leaf residues (5 t DM ha$^{-1}$) was included as an option that is relatively readily available to farmers. Climbing beans and maize were selected as test crops.

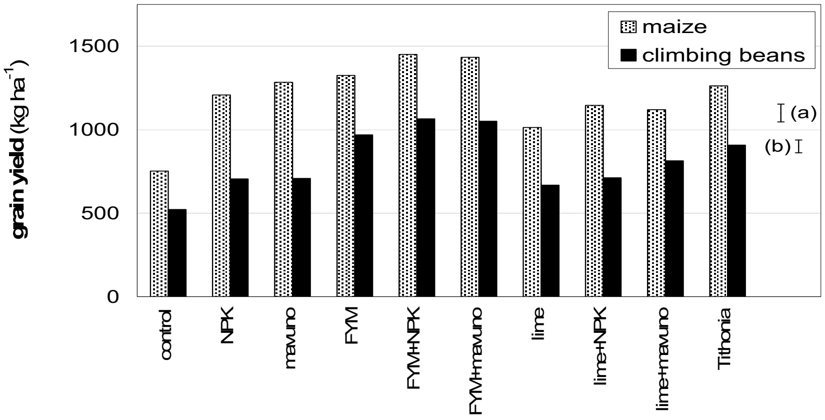

**Figure 18:** Grain yields for climbing beans and maize as affected by different inputs (NPK fertilizer, mavuno fertilizer, farm yard manure, lime and *Tithonia* leaf residues) on the Walungu axis in Sud-Kivu, DRC.

Grain yields were significantly increased by all inputs, except for lime application **(Figure 18)**. However, both maize and bean yields remained in general much below the potential of the crops.

Highest yields observed in one of the more fertile fields were 2.7 t $ha^{-1}$ for maize and 1.8 t $ha^{-1}$ for climbing beans (generally obtained in treatments with combined application of FYM and fertilizer). There was a significant interaction between species, treatment effects and the soil fertility status (not shown); in the poor fields, maize generally failed in all treatments, while climbing beans responded significantly to FYM and fertilizer application. Only in one out of the eight sites, a striking difference could be visually observed between the treatments with NPK application and mavuno application, which suggests a nutrient other than N, P or K was limiting crop growth. In other sites, responses to NPK and mavuno were comparable. However, micronutrient deficiency may have been masked by P deficiency. Currently, specific analyses are conducted on young bean leaves and maize ear leaves to identify potential micronutrient deficiencies.

Maize growth as affected by input application in a demonstration trial in Lurhala, Sud-Kivu, DRC; from left to right: control, NPK (17:17:17) at 20 kg P $ha^{-1}$ and mavuno (NPK enriched with micronutrients) at 20 kg P $ha^{-1}$.

The results from these field trials instigated a series of pot trials, set up between August and December 2007 at the research center of INERA (*Institut National pour l'Etude et la Recherche Agronomique*) in Mulungu, Sud-Kivu, on a wider range of soils from the area to rapidly investigate major nutrient deficiencies occurring on the Walungu axis. Soils were collected from the 0-20 soil layer in fields previously selected for legume evaluation and multiplication, and from fields in randomly selected farmer households during the final characterisation study. While the former two sets of soils were presented by farmer associations for project activities and of variable fertility according to the association's ability to meet the expenses of providing land, the latter soils are typically cultivated by legumes following the local practices. The selected soil collection is considered a representative set of soils used for legume cultivation in the Walungu area.

Six different treatments were imposed in a single replicate: a control without nutrient additions, a reference treatment with additions of all nutrients (396 mg N kg$^{-1}$, 360 mg P kg$^{-1}$, 360 mg K kg$^{-1}$, 210 mg Ca kg$^{-1}$, 92 mg Mg kg$^{-1}$, 42 mg S kg$^{-1}$, 2.9 mg Mn kg$^{-1}$, 1.9 mg Zn kg$^{-1}$, 1.9 mg Cu kg$^{-1}$, 0.6 mg B kg$^{-1}$ and 0.6 mg Mo kg$^{-}$1), 3 treatments with N, P and K omitted respectively, and a treatment with application of N, P and K only (at the same rates as in the reference treatment). The above rates were assumed to eliminate deficiencies for the respective plant nutrients. Following salts were used for the nutrient additions: $KH_2PO_4$, $NH_4H_2PO_4$, $Mg(NO_3)_2.6H_2O$, $NH_4NO_3$, $KNO_3$, $Ca(NO_3)_2.4H_2O$, $MgSO_4.7H_2O$, $(NH_4)_2S0_4$, $ZnCl_2$, $CuCl_2.2H_2O$, $FeCl_3$, $MnCl_2.4H_2O$, $(NH_4)_6Mo_7O_{24}.4H_2O$, and $Na_2B_4O_7.10H_2O$. The pots were filled with 2.5 kg of soil, after which the soil of each pot was mixed with nutrient solutions according to the different treatments. In each pot, 3 maize (*Zea mais* L., cv. Katumani) seeds were sown, and thinned to one plant per pot after one week (1 WAP). Moisture conditions were kept optimal in the course of the trial. The average minimum and maximum temperatures during the growth period equalled 15,6°C and 45,6°C, respectively. Regularly, the height of the plants (i.e. the distance from the plant basis to the highest tip of the three youngest fully developed leafs) was measured. Plants were cut at 38 days after planting (DAP). At harvest the youngest fully developed leaf was cut and dried separately for leaf nutrient analysis. Plant biomass was sun-dried in closed paper bags. Subsequently, plants were oven-dried (65ºC) and weighed.

Treatment differences became apparent at about 3 WAP. At 32 DAP, plant heights in the control and the treatments without P addition were similar and as low as 50 cm, while an average height of 85 cm was observed in the reference treatment. Visual signs of P deficiency were observed in the control and the treatment without P addition, and were very pronounced in all 30 soils (without exception). Dry weights at harvest were more than five times smaller than the reference treatment **(Figure 19)**. In the other treatments with N, K or micronutrients omitted, responses were differential, but no consistent differences with the reference treatment were observed. In some soils, however, maize plants clearly showed to suffer from nutrient deficiencies other than P. Leaf analyses (pending) are required to diagnose these.

Visual symptoms of nutrient deficiency in young maize plants.

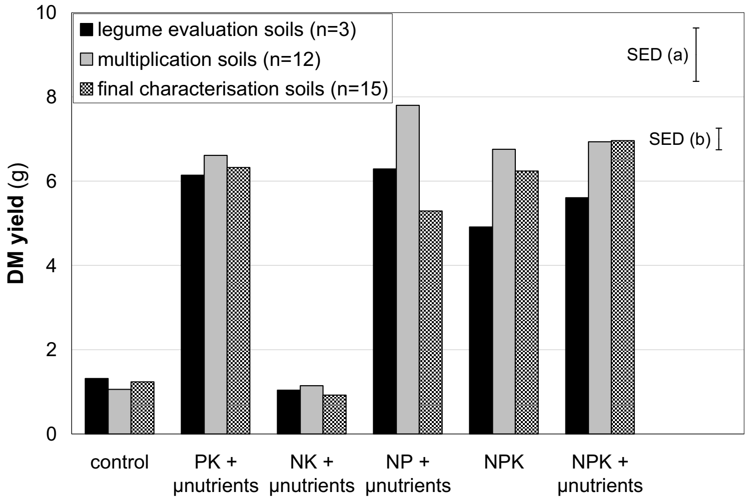

**Figure 19:** Maize dry biomass weight after 38 days of growth, as affected by different nutrient application regimes, observed in a pot trial conducted at INERA-Mulungu, Sud-Kivu, DRC.

No significant differences in maize response were observed between soils used for legume germplasm evaluation, legume multiplication and soils sampled during the final characterization study. The similarity between the soil types was confirmed by soil analysis **(Table 13)**. All soils were similarly characterized by a similar and low organic C content (0.6%), soil pH (5.2) and low cation exchange capacity (6 $\text{cmol}_c\ \text{kg}^{-1}$).

**Table 13:** Soil properties for project soils (sampled in fields for legume germplasm evaluation and multiplication) and final characterization soils (typically cultivated with legumes, sampled in farmers' fields).

| | **org. C** ($\text{g kg}^{-1}$) | **pH** ($H_20$) | **CEC** ($\text{cmol}_c\ \text{kg}^{-1}$) |
|---|---|---|---|
| Project soils | 6.63 | 5.2 | 5.88 |
| Final characterization soils | 5.36 | 5.3 | 6.71 |
| SED | 0.82 | 0.2 | 0.46 |

## Completed Work

### Evaluation of Soybean Grains and Product Quality Challenges and Improvement.

**O. Ohiokpehai**[1]

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Uptake of soybean has remained low in the sub-Saharan African including Kenya leading to persistence of malnutrition in the region and its attendant devastating health and productive standards. It is against this background that the CIAT-TSBF is out to promote production of soybean in order to enhance soil improvement through the production of soybeans among the rural households, particularly those affected with HIV and AIDS. Under its Soybean project of using nutrition and utilization to promote soybean productivity CIAT-TSBF has undertaken research to identity proper seeds and level of fertilizer use that meet the farmer preferences and socio-environmental circumstances. Also grain quality was determined through the chemical analysis of the moisture content, protein, fat and ash and physical characteristics of eleven varieties. Finally soybean was incorporated into local foods and farmer preferences evaluated. Results of grain analysis of the eleven TGX varieties compared to local ones showed that three varieties of TGX belonged to high protein category. The other varieties belong to medium protein content category. Also all TGx varieties evaluated had small grain ideal for household processing and it is important that large seeded varieties were developed for the large scale industrial use as Kenya already has a market for large grains.

## *Progress towards achieving output level outcome*

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

The objective of Output 1 is to develop methods and principles that underlie efforts to improve the health and fertility of soils. Such international public goods (IPGs) foster innovative soil management strategies and inform the technology development and adaptation processes conducted in Output 2. This output has two aspects: one is the improved understanding of the process informing the development of technologies and systems that improve the fertility of soils and soil health; and the second aspect concerns the contribution of the improved soil health and fertility to resilient production systems and sustainable agriculture. Development of principles, concepts and methods involve continuous and detailed review of the literature to identify key research questions and research gaps that are translated into laboratory, greenhouse and field experiments with increasing on-farm research activities. Robust techniques for analyzing heterogeneity of socio-economic and biophysical factors influencing soil fertility management and soil fertility outcomes have now been developed, tested, and applied in a diversity of environments and socio-cultural settings. Research has focused more and more on land management practices, reduced-till and crop-livestock systems, and their possible impacts of soil fertility and the natural resource base. Impacts evaluated range from changes in populations of soil microorganisms, changes in soil organic matter, soil P pools and water infiltration, changes in nutrient use efficiency in response to organic and inorganic nutrient sources, to changes in nutrient and resource flows at the farm and village scales in Africa.

Greater insights have been gained by the careful consideration of the agro-ecological and socio-economic contexts where these land management practices are tested thus increasing our capacity to develop relevant technologies and methods for sustainable land management. The studies into resource allocation on farm and soil fertility gradients within and across farms, are an example. Several studies on fallow management (looking at options for ISFM/nutrient management strategies and the effect on crop performance, legume management for recovery of soil fertility status, effect of manure application on soil organic matter fractions and soil health status and the like) have greatly contributed to our insight on how such technologies can be applied to improve the natural resource base within the context of the farming system. Studies into historical land management practices help to identify possible new technologies and practices (e.g. work on conservation agriculture). In many ways these studies, apart from developing principles and concepts, are at the same time a test of technologies developed, like the effect of dual purpose legumes on soil fertility.

Investigation of the applicability of conservation agriculture in different systems has confirmed opportunities for introduction of no-till systems on the Minombo woodland savanna of Southern Africa. Though the basic principles of conservation agriculture are known, their short and long-term effects on the natural resource base, and the applicability to different management systems need to be further investigated.

In relation to below-ground biodiversity (BGBD) and the role of soil organisms in maintaining soil fertility and sustaining agricultural production, the inventory of BGBD in many different benchmark areas has contributed significantly to our insights of what is actually there (including new species discovered) and the impact of changing land use and on the abundance and diversity of soil organisms belonging to various functional groups. The BGBD project has successfully concluded its first phase and a publication summarizing common standard methodologies for soil biodiversity inventory has been completed after validation across carefully selected benchmark sites in Brazil, India, Indonesia, Ivory Coast, Kenya, Mexico and Uganda. Continuing studies into the mechanisms by which soil organisms interact with the other biological components helps us to understand the role and function of these particular soil organisms (e.g. suppression of soil borne pest and diseases), as indeed a basis for developing biological technologies.

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

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

## *Progress towards achieving output level impact*

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

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

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