Output 2
Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical and socioeconomic processes

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Rationale

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

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

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

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

Key research questions:

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

Highlights

- ∉ In a major banana production area in Central Kenya, there was a clear indication that fertilizer affects banana growth and production. The ratios and types of fertilizer determined the rate of growth, maturity and size of banana bunches. Aboveground biomass, banana maturity and bunch weights were greatly enhanced by application of full fertilizer rates. Potassium fertilizer was important for bunch formation, and N affected biomass production. Phosphorus and micronutrients were important in enhancing all growth parameters.

- ∉ Even though agriculture is the main source of income and other aspects of improved livelihoods in western Kenya, households tended to pay less attention to farm input-related expenses (mineral fertilizers, organic manure, seeds, etc.) when allocating their little financial resources. Preference is often given to items such as paraffin, food, health and medication and social contributions

- ∉ Wealth inequality was found to be high among rural households in western Kenya. This was in terms of both household wealth (with a *Gini-coefficient* of 0.52) and per capita wealth (with a *Gini-coefficient* of 0.55).

- ∉ Intercropping is one of the ways of ameliorating the productivity of land and other inputs and can be used by small-scale farmers primarily to increase the diversity. For production of quality and high yielding grains, the soils must be very fertile. The importance of using double row intercropping system as a best- bet method in increasing food security high in nutritional value was confirmed**.**

- ∉ Showed that the rotational systems (maize-soybean green manure and maize-pastures) improved the soil conditions to implement the no-till or minimum tillage systems on Colombian savanna oxisols.

- ∉ Ex-ante evaluation of the costs and benefits of different options of introduced crop-livestock systems at the farm scale to quantify the impact of diversified production systems indicated that the economic impact of the improved systems with the build up of an arable layer at the regional level was estimated at US$239 million.

- ∉ Found significantly higher maize grain yields under no-till agropastoral systems as compared to the same systems under minimum tillage and showed that maize yields on native savanna soils were markedly lower than in the rest of the agropastoral systems, indicating the need for improved soil conditions in subsoil layers for root growth of maize.

- ∉ Showed that the residual effects of building an arable layer can be detected on subsequent crop yields of maize.

- ∉ Showed that the apomictic natural accession *B. brizantha* CIAT 6294 and the apomictic hybrid cultivar Mulato 2 (CIAT 36087) could produce greater amounts of live shoot biomass (forage) with maintenance fertilizer application. The productivity of these two genotypes was superior to *B. decumbens* CIAT 606 and this superior performance was associated with coarse root development.

- ∉ Showed that in Quesungual Slash and Mulch Agroforestry System (QSMAS) systems soil losses by runoff were greater at the beginning of the rainy season than during the rainy season except in slash-and-burn system where soil losses occur all the time and even raise at the end of the rainy season.

- ∉ Showed that the presence of stones in the soil is one of the factors improving the performance of Quesungual system during the dry season. Found that soil with stone proportion of up to 60% do not restrict total biomass (shoot + root) production of maize with high and intermediate frequency of water application but the presence of stones between 40 to 60 % volume of soil can markedly improve soil moisture retention and therefore improve maize plant growth under low frequency of water application that simulates drought conditions.

- Studies on soil physical characterization and water dynamics in the fallows of Quesungual system indicated very highly significant positive correlation between root biomass and available water holding capacity in soil.
- Showed that Quesungual system of older than 10 years minimized soil losses by reducing runoff and improving water infiltration.
- Preliminary studies on nitrogen and phosphorus dynamics in Quesungual systems showed that the total pools of N and P were maintained or even incrased in the plots of over ten years of the use of the system.
- Quantified fluxes of greenhouse gases (GHG), nitrous oxide (N_2O) and methane (CH_4) in three Quesungual farms during two years and found that these farms were sinks for methane.
- Estimated firewood use in rural and urban communities in Candelaria of southern Lempira, Honduras and found that Quesungual system is an important source of firewood for domestic consumption and farmer preferred trees for firewood are *Cordia alliodora* and *Diphysa americana*.
- Established Quesungual plots in La Danta watershed in Somotillo, Nicaragua to compare with crop residue management, slash-and-burn and fallow systems and monitored maize yield for two seasons to validate the system.

Output target 2007

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

Completed work

Arbuscular mycorrhizal dependency of different tissue cultured banana cultivars

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The mycorrhizal dependency of different tissue cultured banana cultivars on AMF was determined under glasshouse conditions. Five most popular commercial dessert banana cultivars from Kenya and four plantain cultivars from Uganda were treated with four AMF species (*Glomus etunicatum, G. intraradices, G. mosseae* and *Gigaspora albida*) and a control. The two-factor experiment was laid out in randomised complete block design (RCBD) with each treatment replicated five times. Mycorrhization was done during the hardening stage. After deflasking, the banana cultivars were planted into hardening trays and maintained under mist conditions. Modified Hewitt nutrient solution was applied twice per weeks at the rate of 100 ml pot^{-1} and plants were maintained for eight weeks. Three sequential harvests were done at 8, 18 and 22 weeks after inoculation at which four plants per treatment were harvested. After 8 weeks the remaining plants were transplanted into 1 litre plastic containers. At each harvest, fresh weight of shoots and roots and leaf surface area were recorded. Fresh roots were then processed to assess mycorrhizal colonization. Relative mycorrhizal dependency (RMD) of the various cultivars was calculated. The oven-dried shoot samples were analysed for macronutrients. Analysis of variance with GENSTAT version 8 analytical package was carried out on all data to test the treatment effects on the various measured parameters. Means were separated by Fisher's test ($p \leq 0.005$). In general, banana plantlets are highly dependent on mycorrhizae association with plants inoculated with *Glomus* species performing better than those inoculated with *Gigaspora albida* and the control in all parameters taken (Table 19). There were significant variations in effectiveness of the AMF species and response of banana cultivars due to the different RMD observed (Table 20). Shoot samples of plants inoculated with *Glomus* species had significantly higher nutrient contents compared to the *Gi. albida* and the non-inoculated plants (Table 21).

On-farm Interaction between soil fertility factors, farmer management, pest and diseases on the yields of banana (*Musa* spp.) in Maragua district of Kenya.

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The phenomenon of progressive yield decline in bananas has been reported extensively world wide. Several causes have been suggested, which include pests, diseases, farmer management as well as decline in soil fertility. However, the real causes have not been clearly understood, since most studies have not been able to capture the interactive influences between these yield decline causes. Since the farmer attempts to achieve higher yields by manipulating the crop's agro-ecosystem, this study aimed at capturing the causes of yield variability within the farms, and amongst farmers of different resource endowment levels. A 14 month on-farm monitoring was done in Maragua district, Central Kenya. The farm gradient was from upper, mid and lower part, close to away from the homestead. Ten randomly selected farms of low, middle and high income farmers and a popular banana cultivar, the Giant Cavendish, were monitored. Environmental factors such as soil nutritional status within the banana mats, allometric measurements of plant growth, pests and disease incidences and plant performance and detailed farmer management practices were recorded and quantified.

Table 19. Effect of *Glomus* and *Gigaspora* species on the development and colonization of combined banana cultivars at 8 (n = 4), 18 (n = 3) and 22 (n = 3) weeks after inoculation.

AMF	Ht (cm)	SFW (g)	SDW (g)	RFW (g)	LSA (cm^2)	AMF F%	AMF I%
22 weeks after inoculation							
Control	2.41 a	1.99 a	0.39 a	3.19 a	39.2 a	0.00 a	0.00 a
Gi. albida	2.08 b	1.45 a	0.34 b	2.28 b	40.6 a	0.00 a	0.00 a
G. mosseae	6.18 c	9.33 b	1.44 c	8.63 c	175.1 b	65.56 b	68.14 b
G.intraradices	7.36 d	12.61 c	1.90 d	10.29 d	234.5 c	84.42 c	79.25 c
G.etunicatum	6.92 e	12.08 c	1.95 d	9.96 d	219.5 d	80.16 d	78.32 c

Fisher's test (p<0.05) Orthogonal comparisons of treatment means. Within each column numbers followed by the same letter are not significantly different.
Ht = Height; SFW = Shoot fresh weight; SDW = Shoot dry weight;
RFW = Root fresh weight; LSA = Leaf surface area;
AMF F% = AMF frequency percent; AMF I% = AMF intensity percent

Table 20. Relative Mycorrhizal Dependency (%) of banana cultivars 22 weeks after inoculation with different AMF species.

Relative Mycorrhizal Dependency (RMD %)			
AMF species	***Glomus mosseae***	***Glomus intraradices***	***Glomus etunicatum***
Cultivars			
Grand Nain	32.24 ab	44.12 ab	37.97 ab
Giant Cavendish	41.04 ab	45.53 ab	46.10 ab
Valery	49.66 a	52.89 ab	60.95 a
William's Hybrid	50.23 a	54.67 a	37.48 ab
Kampala	37.95 ab	18.14 bc	50.31 a
Kisansa	23.47 abc	37.88 abc	30.06 ab
Nakitembe	6.99 bc	51.72 ab	29.02 ab
Mbwazirume	23.32 abc	6.13 c	8.20 b
Mpologoma	7.11 bc	40.16 ab	54.07 a

Table 21. Nitrogen and Phosphorus content in shoots of different banana cultivars.

AMF species / Time	Nitrogen (mg kg^{-1})	Phosphorus (mg kg^{-1})
Control	982 a	23.3 a
Gi. Albida	698 b	20.7 a
G. mosseae	2635 c	127.5 b
G. intraradices	3503 d	191.0 c
G. etunicatum	3756 d	171.1 c

Fisher's test (p<0.05). Within each column numbers followed by the same letter are not statistically different. 22 weeks (n = 3).

Soil factors were the most yield limiting factors accounting for 67% of yield limitations, farmer management factors 23% and pests and diseases accounting for only 10% of all yield limitations. The soil constraints were low pH, imbalances between K and Mg, inadequate levels of soil N, and high C/N ratios in the subsoil. Farmer management constraints were excessive leaf pruning (16%) and high plant densities (7%). The most prevalent pest was nematodes (*Radopholus similes*) which caused only 3% yield limitations and a condition similar to yellow sigatoka (*Mycosphaerella musicola*) which accounted for only 7%. There was no difference in yields amongst farmers of different resource levels, but the yields nearest the homesteads were significantly higher than the yields furthest from the homesteads. However, the causes of better spatial yield trends were different amongst the different resource endowment levels.

The poorer farmers were favored by higher soil N levels and higher soil pH, whereas the richer farmers were favored by better management but constrained by low soil pH and low soil N. Improving yields among poor banana farmers should target at improving their management of the plantations, whereas the richer farmers should focus more on soil improvements. The mid-class farmer had a mix of the problems facing the poor and the rich, hence had the most yield limitations, but the highest average yields. Research for banana yield improvement in Central Kenya should focus more on the complex interactions between K and Mg at various pH, soil organic matter management. Research on optimal plant densities coupled with optimal number of leaves to leave on the plant is vital in an area where zero grazing threatens plant leaf numbers. Pest and disease research should be aimed at areas where soil problems are not critical.

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

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Although much soil fertility related studies in EA highland banana systems have been conducted, knowledge on optimal nutrition for banana production within the smallholder production context in East Africa is virtually non-existent. There is a lack of basic knowledge on how much nutrients the AAA-EA banana plant requires, what its potential production is under well fertilized conditions, what nutrients are limiting plant growth in different areas, and how much fertilizer needs to be applied to achieve the economic optimum for a certain target yield. The objectives of the trial are to (1) identify what nutrients are limiting highland banana production on the trial sites, (2) to determine what the nutrient requirements are of highland bananas, (3) to identify/confirm what the critical and optimal nutrient concentrations are in different plant parts of highland bananas, (4) to estimate potential production of highland cooking banana, and (5) to determine recovery rates of fertilizers in highland cooking bananas, in order to allow the calculation of cost-benefits of different fertilizer recommendations.

The trial was established in December 2004 with Giant Cavendish as the cultivar used. The design applied was a complete randomized block design with 4 replications, and the fertilizer rates recommended are:

- N – 400 kg ha^{-1}, ½N – 150 kg ha^{-1}; applied in the form of Urea
- P – 50 kg ha^{-1}; applied in the form of TSP
- K – 600 kg ha^{-1}, ½ K_2O – 250 kg ha^{-1}; applied in the form of KCl
- Micronutrients: Mg – 60 kg ha^{-1}, Zn – 6 kg ha^{-1}, S (in Zn and Mg sulfates),
- Molybdenum - 0.5 kg ha^{-1} (in Sodium Molybdate), Boron – 1 kg/ha (in Borax)
- Pesticide: chemical treatment against nematodes and weevils (none of the treatments were treated except a control and a treatment with all nutrients applied – referred to as 'all-pest' and 'con-pest' in the text below).

Plant spacing is 3x3 m, resulting to an individual plot size of 21x15 m or 35 plants per plot, with measurements taken from only 15 plants per plot. Individual plots within the same block are separated by a 4m wide grass strip. Observations and samplings made in the trial include: (1) plant growth (girth, height, number of functional leafs, Leaf Area Index – based on estimated leaf size) at regular intervals (e.g. every 2nd/3rd month), (2) date of important growth stages (flowering, maturity), (3) incidence of diseases (time of occurring, which leafs affected and the severity in terms of leaf area % affected, or severity), (4) root nematode samples at flowering of 1 plant in each plot + measure root necrosis at flowering of the sampled plants, (5) composite samples of 3rd leaf, the 3rd midrib and the 7th petiole at large suckering stage - 6 months (for midrib and petiole maybe only in first year), just after flowering when the first male flowers appears, and at maturity, (6) fresh weight of different above-ground plant parts (pseudostem, leafs, and different bunch parts) at harvest, (7) sub samples of different plant parts at harvest for determination of humidity % and for chemical analysis in the lab, and (8) fruit quality/maturation measurements (post-harvest quality).

Fertilizer application and types of combinations affected plant growth (Figure 25), bunch maturity (Figure 26), and bunch weight (Figure 27) with the least observed in treatments without fertilizer and plots with incomplete fertilizer ratios. Fertilizer application significantly ($p < 0.001$) affected bunch weight. Absence of phosphorus, micronutrients and nitrogen affected plant growth, rates of banana maturity and weight of bunches. Treatments with full fertilizer rates with or without pesticides consistently showed the highest growth, maturity of bunches and bunch weights. Absence of N resulted in slow growth, slow maturity and lower bunch weight. There is also clear evidence K is essential in bunch formation since the absence of K reduced the rate of bunch formation.

There is a clear indication that fertilizer affects banana growth and production. The ratios and types of fertilizer also determine the rate of growth, maturity and size of banana bunches. Above ground biomass, banana maturity and bunch weights are greatly enhanced by application of full fertilizer rates.

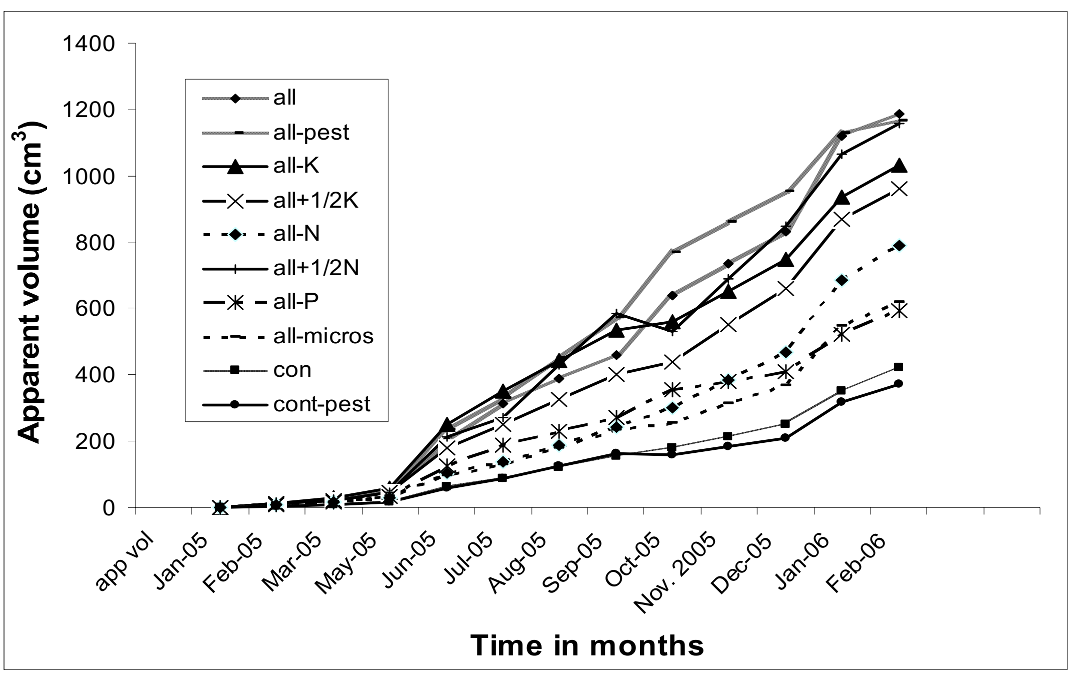

Figure 25. Apparent volume of banana bunches from January 2005 to January 2006.

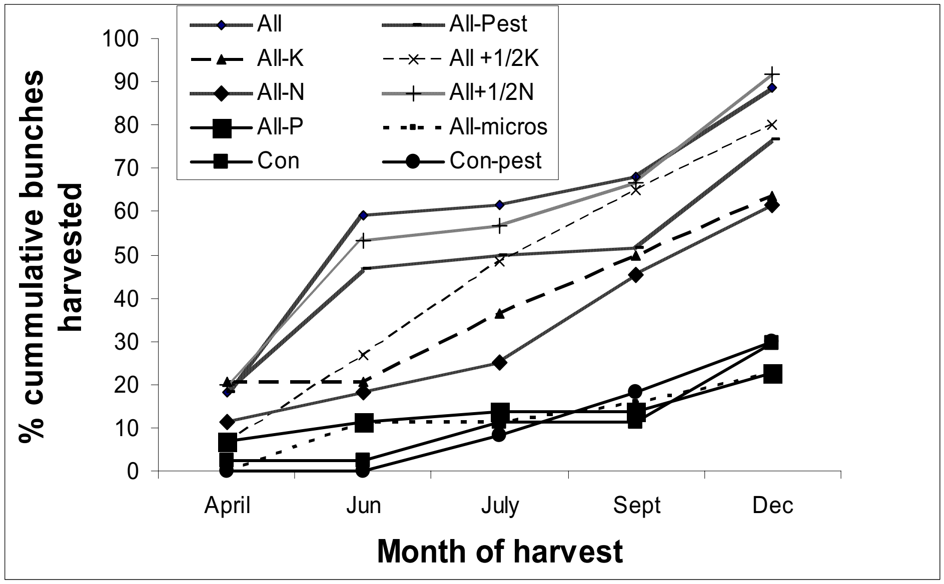

Figure 26. Percentage cumulative banana bunches harvested from each fertilizer treatment.

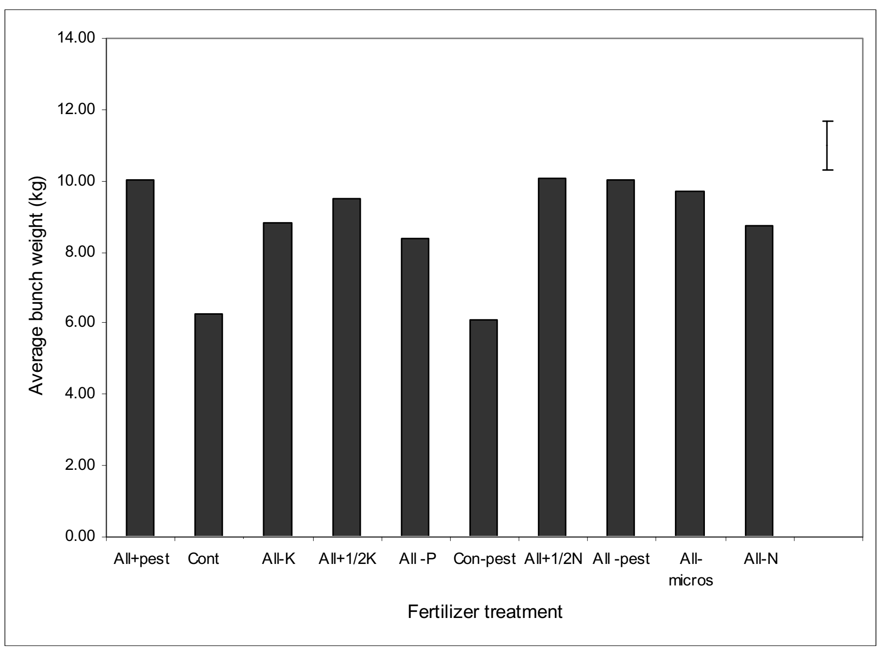

Figure 27. Average bunch weight of bananas in ten fertilizer treatments. Error bar is SED.

Potassium fertilizer is important for bunch formation, and N seemed to affect biomass production. Half rate N was however effective enhancing growth, maturity and bunch weight similar to full fertilizer rates. Phosphorus and micronutrients are important in enhancing all the three parameters. It is evident that fertilizer combinations and rates are important in banana production.

Output target 2007

ü ***Benefits of agropastoral systems on crop productivity and soil quality quantified in acid soil savannas***

Published work

Basamba[1], T., Barrios[2], E., Rao[2], I.M. and Singh[1], B.R. (2006) Tillage effects on maize yield in a Colombian savanna oxisol: Soil organic matter and P fractions. Soil and Tillage Research 91: 131-142.
[1]Norwegian University of Life Sciences, Norway; [2]TSBF-CIAT, Cali, Colombia
Abstract: Soil organic matter (SOM) and phosphorus (P) fractions play a key role in sustaining the productivity of acid-savanna oxisols and are greatly influenced by tillage practices. In 1993, a long-term experiment on sustainable crop rotations and ley farming systems was initiated on a Colombian acid-savanna oxisol to test the effects of grain legumes, green manures, intercrops and leys as possible components that could increase the stability of systems involving annual cereal crops. Five agropastoral treatments (maize monoculture – MM, maize-soybean rotation – MRT, maize-soybean green manure rotation – MGM, native savanna control – NSC, and maize-agropastoral rotation – MAP) under two tillage systems (no till – NT and minimum tillage – MT) were investigated. The effects of NT and MT on SOM and P fractions as well as maize grain yield under the five agropastoral treatments were evaluated. Results showed that soil total carbon (C), N and P were generally better under no-till as compared to minimum-tilled soils while P fractions were also generally higher under no-till treatments. SOM fractions did not show any specific trend. Seven years after establishment of the long-term ley farming experiment (5 years conventional tillage followed by 2 years alternative tillage systems), MT resulted into moderately higher maize grain yields as compared to NT. The MGM rotation treatment had significantly higher values of maize yield under both tillage systems (4.2 Mg ha^{-1}) compared to the NSC (2.3 Mg ha^{-1}). Results from this study indicate that the rotational systems (maize-soybean green manure and maize-pastures) improved the soil conditions to implement the no-till or minimum tillage systems on Colombian savanna oxisols.

Basamba[1], T.A., Amézquita[2], E., Singh[1], B.R. and Rao[2], I.M. (2006) Effects of tillage systems on soil physical properties, root distribution and maize yield on a Colombian acid-savanna Oxisol. Acta Agric. Scand. 56:255-262.
[1]Norwegian University of Life Sciences, Norway; [2]TSBF-CIAT, Cali, Colombia
Abstract: Tillage system may affect many soil properties, which in turn may alter the soil environment and consequently may impact on root growth and distribution, and crop yield. In 1993, a long-term field experiment on sustainable crop rotation and ley farming systems was initiated on a Colombian acid-savanna Oxisol to test the effects of grain legumes, green manures, intercrops and leys as possible components that could increase the stability of systems involving annual crops. In the present study, five agropastoral treatments (maize monoculture, maize-soybean rotation, maize-soybean green manure rotation, native savanna, maize-agropastoral rotation) under two tillage systems (no tillage and minimum tillage) were investigated. Lower bulk density and higher total porosity for all treatments and soil layers was found in no-till as compared to the minimum tillage system. Between the two tillage systems, significantly higher maize grain yields ($P<0.1$) were obtained under no-till agropastoral treatments as compared to the same treatments under minimum tillage. Maize yields on native savanna soils were markedly lower than in the rest of the treatments, indicating the need for improved soil conditions in subsoil layers for root growth of maize.

Completed work

Strategies and opportunities for intensification and diversification of agropastoral systems in neotropical savannas of Colombia

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The world's tropical savannas represent almost 43% of the arable land, out of which 27% is located in tropical America. The savannas in South America cover approximately 270 million hectares (Mha), distributed as follows: 207 Mha in Brazil, 28 Mha in Venezuela, 17 Mha in Colombia, 14 Mha in Bolivia and 4 Mha in Guyana. These savanna areas represent one of the last frontiers for agricultural expansion in the world. Starting in the 1970's, Brazil, Colombia and Venezuela, experienced the replacement of native grasses for improved *Brachiaria* based pastures and this resulted in 2-fold increase in liveweight gain per animal and up to10 to 15-fold increase in liveweight gain per unit area.

These grass alone pastures in the absence of proper management including application of maintenance fertilization led to pasture degradation. This degradation was further aggravated by susceptibility of widely planted grasses to an insect known as spittlebug. A major effort was made to introduce acid-soil adapted forage legumes to increase nitrogen supply to the system and improve and sustain higher levels of livestock production. However, the legume-based pasture technology was not widely adopted by farmers due to lack of persistence of the legume component over time and limited availability of seed in the market.

Following the emphasis on developing legume options, research in the last decade focused on developing improved grass cultivars (hybrids of *Brachiaria*) that combine adaptation to major biotic and abiotic constraints and crop components with acid soil adaptation (resistance to high levels of aluminum and tolerance to low levels of phosphorus), such as upland rice, maize, sorghum and soybean. This was a major collaborative effort involving CGIAR centers (CIAT, CIMMYT, and ICRISAT) and other partners including NARS (CORPOICA) and local universities (Universidad de los Llanos).

These forage and crop components were the entry points for developing more intensive and diversified agropasotoral systems. Monocropping systems with high levels of inputs and excessive cultivation (disc harrowing) are not sustainable since they cause deterioration of soil physical, chemical and biological properties as well as escalation of pest and disease problems. Alternative systems incorporating components that attenuate or reverse the deleterious effects of monocultures are required, and biophysical measures of sustainability need to be developed as 'predictors' of system 'health' to sustain agricultural production at high levels while minimizing soil degradation. Grain legumes, green manures, intercrops and leys are possible system components that could increase the stability of systems involving annual crops. However, for these more intensive systems to be productive and sustainable soil management strategies needed to be developed.

Soils in the Llanos of Colombia are classified as Oxisols and Ultisols characterized by low levels of soil nutrients, low exchangeable ion capacity and high levels of soil acidity and aluminum saturation. Available phosphorous levels are very low and limit pasture and crop productivity. When these soils are subject to mechanized agriculture, they rapidly lose their initial physical structure. The solution to manage these soils in a productive and sustainable way is by developing an arable layer using vertical tillage (chisels) to correct the physical conditions, adding lime and fertilizers to correct the chemical conditions, and using improved forage and crop components adapted to these conditions so that the fertilizer and the amendments added could promote vigorous root growth (pastures) to improve soil biological activity and stabilize soil physical structure.

Results from the long-term field experiments in the Llanos of Colombia indicated that agropastoral systems based on acid soil adapted and deep-rooted tropical forage grasses are markedly superior to crop rotation for building an arable layer for infertile savanna Oxisols. Using this integrated soil management technology it was possible to improve profitability and sustainability of agropastoral systems in the Llanos of Colombia. The costs and benefits of different options of introduced livestock-crop systems were evaluated *ex-ante* at the farm scale to quantify the impact of diversified production systems. The economic impact of the improved systems with the build up of an arable layer at the regional level was estimated at US$239 million.

By using the concept of building an arable layer and combining this soil management technology with acid soil adapted cultivars of both forages and crops in agropastoral systems, farmers have the tools and technologies to transform the Colombian savannas. However, social insecurity and lack of infrastructure at present limit the rate of adoption of these innovations. While the overall research objective for the Latin American savannas is to improve the economic and ecological sustainability of crop/livestock systems, the major challenge is to encourage national leaders and the international community to continue supporting research efforts for the sustainable development of these acid soil savannas.

Residual effect of different systems of construction of arable layer on maize yield in the Llanos of Colombia

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Investigations carried out in the acid soil savannas of Colombia by CIAT and CORPOICA demonstrated that physical, chemical and biological conditions of soil in native savannas doesn't offer an optimum soil environment for crop production. Therefore, efforts were made to stimulate the formation of a productive arable layer that allows the development of conservation agriculture suitable for no-till systems to sustain crop production. The aim of this study was to document the residual effect of the different systems of construction of an arable layer on the grain yield of maize.

The study consisted of the sowing maize on six hectares of a farm in Matazul located in the municipality of Puerto López (Meta) at 160 masl. Soils are classified as Tropeptic haplustox isohypertermic kaolinitic.
This study was based on previous special project funded by PRONATTA from 2001 to 2003 that included a field experiment on two soil types (textures) with a combination of three factors: 1) three different agropastoral systems (crop-pasture; crop-pasture-legume; monocropping; 2) two sources of calcium and magnesium (dolomite; sulcamag); and 3) two depths of tillage with rigid chisels (30 and 45 cm soil depth), for a total of 12 treatments. After the completion of the previous study in 2003 with the 12 treatments, the whole experimental area was planted with the cover legume crop of Kudzu and was left fallow in 2005. Maize hybrid Pioneer 3041 was sown in 2006 on the previous treatment plots with direct sowing to test the residual effects of building an arable layer with different systems. Maize grain yields were determined after harvest.

Application of dolomite + sulcamag was better than application of dolomite alone in improving maize yield, particularly with tillage up to 45 cm soil depth (Figure 28). Maize yield was better with crop-pasture and crop-pasture-legume plots than with monocropping plots, particularly with deep tillage.

Results from this study showed that the residual effects of building an arable layer can be detected on subsequent crop yields of maize.

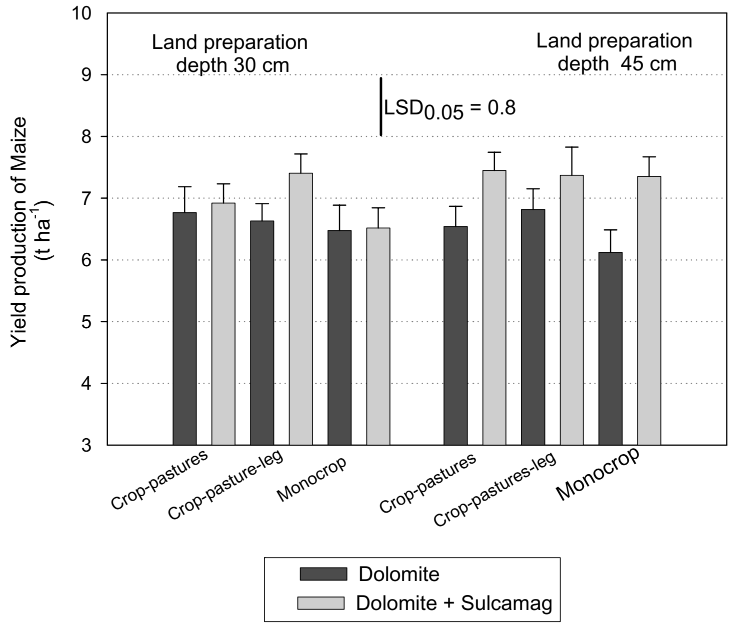

Figure 28. Effects of land preparation at two soil depths (30 or 45 cm) and application of two sources of calcium and magnesium (dolomite or dolomite + sulcamag) on maize grain yield.

Root distribution and forage production of adapted *Brachiaria* grasses in acid soil savannas of Colombia

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Brachiariagrasses are key components of agropastoral systems in acid soil savannas of Colombia. Previous research on shoot biomass production and shoot nutrient uptake of *Brachiaria* genotypes in the Llanos of Colombia showed differences in adaptation of *Brachiaria* species to these acid soils. It has been reported that *Brachiaria decumbens* cv. Basilisk, *Brachiaria brizantha* cv. Marandú, *Brachiaria brizantha* cv. Toledo and *Brachiaria* hybrid cv. Mulato 2 could persist and be productive over time with maintenance fertilizer in contrast to *Brachiaria ruziziensis* 44-02 which showed poor adaptation to acid soils after 1 year of establishment. The objective of the present study was to evaluate the differences in root distribution of well adaptated and poorly adapted brachiaria grasses and the impact of root development on forage production over time. We evaluated the impact of 6 *Brachiaria* genotypes and their root attributes (biomass production, length and specific root length) on forage production.

A field study was conducted at Matazul farm in the acid soil savannas of Colombia for 4 years. Six *Brachiaria* genotypes with variable adaptation to acid soils (two *Brachiaria* accessions *B.decumbens* CIAT 606 = cv. Basilisk, *B. brizantha* CIAT 6294 = cv. Marandú, and four *Brachiaria* hybrids CIAT 36087 = cv. Mulato 2, BR98NO/1251, BR99NO/4015 and BR99NO/4132) were sown with two initial levels of fertilization ([kg ha^{-1}] low = 20 P, 20 K, 33 Ca, 14 Mg and 10 S; high = 80 N, 50 P, 100 K, 66 Ca, 28 Mg, 20 S, 2 Zn, 2 Cu, 0.1 B and 0.1 Mo and half of these amounts were applied for every 2 years as maintenance fertilization). Shoot biomass (forage) production was evaluated for 4 years (at the end of the dry and the rainy season of each year) while root distribution was measured at 33 (dry season) and 41 (rainy season) months after establishment.

Differences in production of live shoot biomass (forage) and total (live + dead) shoot biomass among the six *Brachiaria* grasses are shown in Figure 29. Significant differences were not observed in shoot biomass production among the 6 *Brachiaria* genotypes that were evaluated at 3 and 10 months after establishment. Mean value of live (forage) shoot biomass production was 5136 and 1979 kg ha^{-1} at 3 months after establishment for initial fertilizer applications of high and low, respectively. These values decreased to 860 and 601 kg ha^{-1} for high and low fertilizer application, respectively at 29 months after establishment. Later, the apomictic natural accession *B. brizantha* CIAT 6294 and the apomictic hybrid CIAT 36087 had significantly more living and total shoot biomass, followed by the apomictic natural accession of *B. decumbens* CIAT 606 and the hybrid BR99NO/4015. Two hybrids, BR99NO/4132 and BR98NO/1251, had markedly lower production of shoot biomass over time when compared to the other genotypes.

Total root length production during rainy season was twice that of the dry season (Table 22). Root biomass was greater (more than 30%) and finer (25% more specific root length) in the rainy season than in the dry season. Differences among six *Brachiaria* genotypes in root biomass, root length and specific root length distribution across the soil profile at 33 (dry season) and 41 (rainy season) months after establishment are shown in Figure 30. Root biomass and root length decreased at deeper soil profile while the values of specific root length increased indicating the finer root development in deep soil layers. The very well acid soil adapted *B. decumbens* CIAT 606 showed finer root development (higher values of specific root length) in both dry and rainy seasons while the moderately adapted hybrids BR98NO/1251, BR99NO/4015 and BR99NO/4132 developed finer root systems in the rainy season. Cultivar Mulato 2 (CIAT 36087) and CIAT 6294 developed thicker root systems both in rainy and dry seasons as revealed by lower values of specific root length.

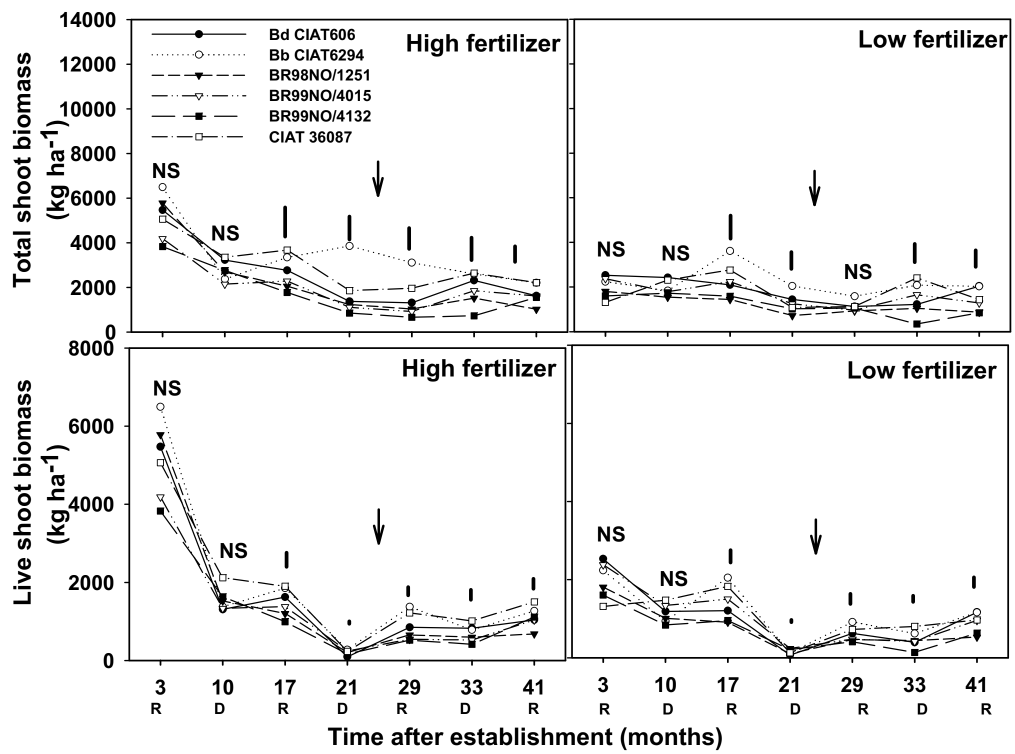

Figure 29. Total (live + dead) and live shoot biomass production (kg ha^{-1}) in 6 *Brachiaria* genotypes evaluated for 4 years. Measurements were made at the end of dry (D) and rainy (R) seasons in each year in an Oxisol of "Altillanura" in Puerto López, Meta (Colombia) with high (High F.) and low (Low F.) initial fertilizer application. The arrows indicate the time of application of maintenance fertilizer at half the levels of initial application. The bars or NS indicate values of $LSD_{p<0.05}$ or no significant differences between genotypes, respectively.

The root biomass of the fine root genotype *B. decumbens* CIAT 606 was markedly lower than the values observed with the two thick root *Brachiaria* genotypes CIAT 6294 and CIAT 36087 (Table 22, Figure 30). Soil from these two genotypes showed slightly lower values of bulk density that could result from turnover of thicker roots. There is need to evaluate the impact of the adapted brachiaria grasses on soil quality parameters over time.

Results from this study indicate that the apomictic natural accession *B. brizantha* CIAT 6294 and the apomictic hybrid cultivar Mulato 2 (CIAT 36087) could produce greater amounts of live shoot biomass (forage) with maintenance fertilizer application. The productivity of these two genotypes was superior to *B. decumbens* CIAT 606 and this superior performance was associated with coarse root development. There is need to test the genotypic differences in root development and persistence with no maintenance fertilizer application. It is possible that fine root development that was observed with *B. decumbens* CIAT 6006 across the soil profile might contribute to its superior adaptation to infertile acid soils with no maintenance fertilizer application that is common in acid soil savannas.

Table 22. Total root biomass (kg ha^{-1}), total root length (km m^{-2}) and mean specific root length (m g^{-1}) (0 to 100 cm soil depth) of 6 *Brachiaria* genotypes evaluated at 33 (dry season - D) and 41 (rainy season - R) months after their establishment with high and low initial fertilizer application to an Oxisol of "Altillanura" in Puerto López, Meta (Colombia).

Genotypes	**Root biomass (kg ha^{-1})**		**Root length (km m^{-2})**		**Specific root length (m g^{-1})**		**Soil bulk density (g cm^{-3})****	
	High Fert.	**Low Fert.**	**High Fert.**	**Low Fert.**	**High Fert.**	**Low Fert.**	**High Fert.**	**Low Fert.**
33 months (D)								
Bd CIAT 606	466	550	2.31	2.74	117	125	1.46	1.44
Bb CIAT 6294	1603	1364	4.07	3.38	44	49	1.43	1.42
BR98NO/1251	1391	1304	3.48	4.12	36	51	1.43	1.41
BR99NO/4015	1206	588	2.71	2.74	55	140	1.45	1.45
BR99NO/4132	609	599	3.30	3.46	64	79	1.42	1.42
CIAT 36087	1267	1149	3.28	3.01	51	49	1.43	1.42
Mean	1090	926	3.19	3.24	61	82	1.44	1.43
LSD(P<0.05)*	652	578	NS	NS	49	NS	NS	NS
41 months (R)								
Bd CIAT 606	816	884	4.127	5.734	132	137		
Bb CIAT 6294	1977	1635	5.006	6.298	42	74		
BR98NO/1251	1910	818	8.114	5.512	69	150		
BR99NO/4015	1161	1150	7.831	8.212	135	116		
BR99NO/4132	1313	987	7.942	7.892	103	100		
CIAT 36087	1572	1832	6.799	6.979	76	56		
Mean	1458	1218	6.637	6.771	93	106		
LSD(P<0.05)	786	482	3.071	NS	83	53		

*The least significant difference (LSD) values or not significant (NS) differences with 95% of probability. ** Mean soil bulk density at 0-40 cm depth.

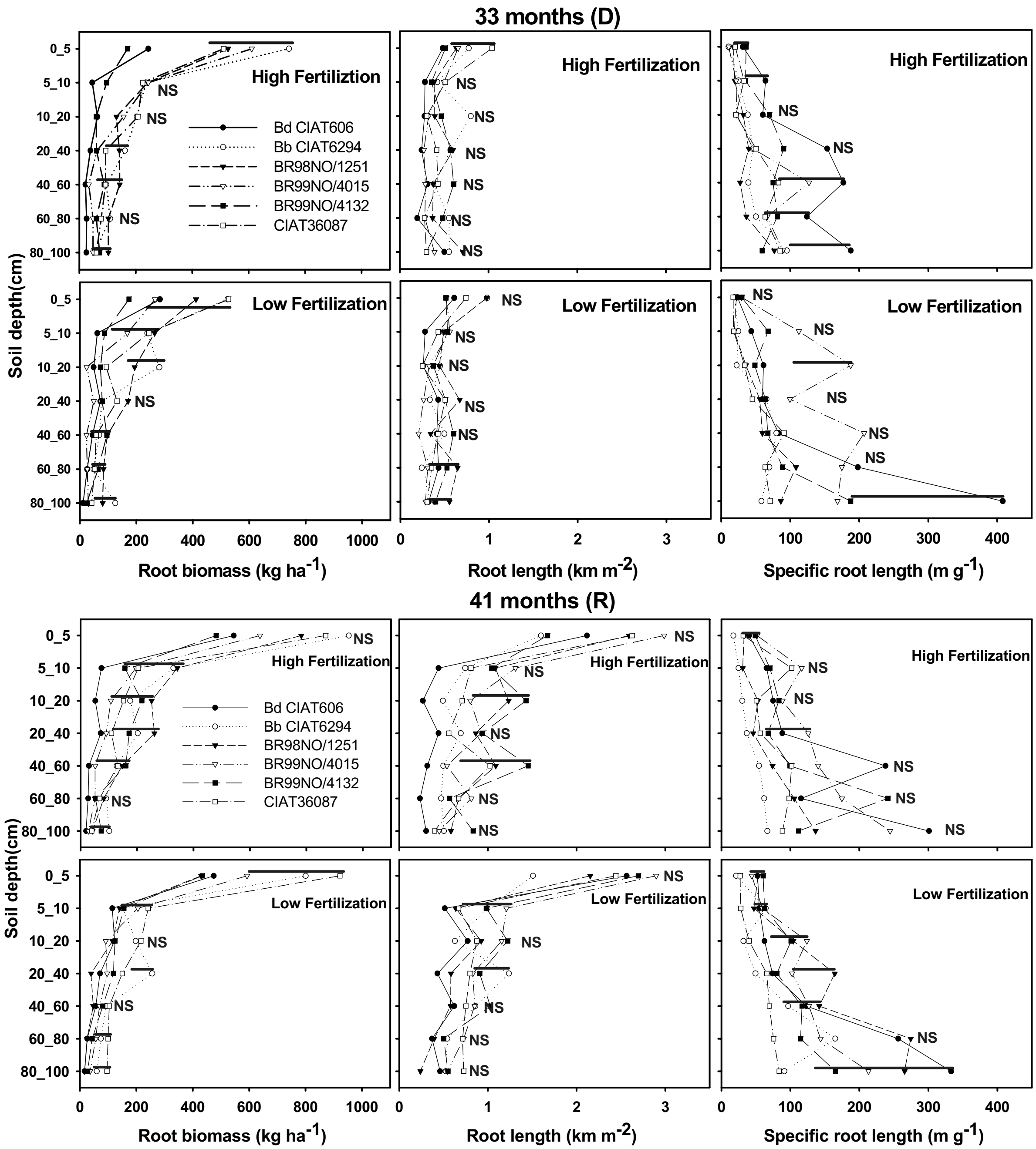

Figure 30. Root biomass (kg ha^{-1}), root length (km m^{-2}) and specific root length (m g^{-1}) distribution across soil profile of 6 *Brachiaria* genotypes evaluated at 33 (dry season - D) and 41 (rainy season - R) months after their establishment with high and low amounts of initial fertilizer application to an Oxisol of "Altillanura" in Puerto López, Meta (Colombia). Bars or NS by depth indicate least significant difference or not significant difference, respectively with 95% of probability.

Output target 2008

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

Published work

Ramisch[1], J., Misiko[2], M.T., Ekise[3], I.E. and Mukalama[3], J.B. (2006) Strengthening "Folk Ecology": Community-based learning for integrated soil fertility management, western Kenya. International journal of agricultural sustainability 4(2): 154 – 168

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

Rufino[1], M.C., Rowe[1], E.C., Delve[2], R.J. and Giller[1], K.E. (2006) Nitrogen cycling efficiencies through resource-poor African crop - livestock systems: Agriculture, Ecosystems and Environment 112: 261 - 282

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

manure handling and storage are generally easier to design and implement than measures to improve crop recovery of N, and should receive much greater attention if overall system NCE is to be improved

Work in progress

Report on the BGBD planning meeting, Xalapa, Mexico, May 25-31, 2006. Internal project document DOC/WRK/06_01 (CD-ROM)

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Earlier during the BGBD project annual meeting held in April 2005, the project coordinator presented a framework for the planning of demonstrations and experimentation with management options for the conservation and sustainable management of BGBD to enhance locally important ecosystem services through direct and indirect manipulation BGBD. This framework was translated into activities or interventions that are subsequently included in the project's logical framework matrix and into activities that form part of the programme of work for the second phase of the BGBD project. These activities or interventions are still described in very general terms. During the planning meeting for the second phase held from the 25th to 31st of May 2006, these were further detailed, to serve as guideline for the country project components to define their own specific activities as far as the demonstration and experimentation with management option for BGBD is concerned.

All country project components are expected to establish demonstration or experimental sites for technology development and demonstration of proven technologies. The proposed technologies are to be subjected to an ex-ante study to assess the feasibility of the proposed technologies, at the same time the pathways need to be mapped through which impact is expected to be generated through these improved technologies. The latter requires the baseline to be established in terms of the socio-economic conditions and livelihoods of the rural population in the benchmark areas. For the demonstrations a systems approach will be adopted, meaning that the inputs (material inputs, labour etc.) and outputs (yield, biomass, return to labour, etc.) will be monitored. At the same time the soil condition and BGBD will be monitored to assess changes to soil ecological system and functioning of the soil ecosystem. The latter will be done through measurement of soil biological component, incidence and monitoring of soil borne pest and diseases, soil structure and aggregate stability, water holding capacity, water infiltration rates, soil organic carbon and other techniques and indicators to assess the soil (biological) quality. The management options that will be demonstrated or experimented with will relate to tillage operations, soil organic matter amendment through various ways (application of manure, composting, crop residues, etc.), to changes in the cropping system (crop rotations, intercropping, etc,) and through direct inoculation (mycorrhiza inoculants, beneficial and antagonistic fungi, earthworms etc.). Apart from the demonstrations, specific experiments will be carried out that target BGBD in relation to specific ecosystem processes, like soil structure modification, carbon sequestration, nutrient cycling or other.

Country project components are obliged to define and plan for the demonstrations in detail such that the related activities can be included in the programme of work, that is to be part of the Memorandum of Agreement between TSBF as the executing institution and the implementing institutions in the countries concerned. In 2006 the MoA with two of the CPCs were finalized.

Output target 2008

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

Work in progress

Quesungual Slash and Mulch Agroforestry System (QSMAS)

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Hillsides constitute an important agroecosystem in humid and sub-humid tropics. In Honduras, hillsides comprise over 80% of the territory and it is within this area that 75% of annual crops (maize, beans and sorghum) are produced. Stagnation of agricultural productivity and rapid population growth have resulted in uncontrolled expansion of agriculture and extensive cattle ranching into primary forest areas on hillsides, causing high rates of deforestation, soil and water losses by erosion and runoff, and increased soil compaction, accelerating the process of soil degradation. Slowing agricultural expansion and reversing land degradation while increasing food production and accessibility, is a sound strategy to improve both rural livelihoods and natural resource management in hillsides of Honduras and other tropical and sub-tropical regions.

The Quesungual Slash and Mulch Agroforestry System (QSMAS) has been a major production system to achieve food security by resource poor farmers of the Lempira department, formerly the poorest region in Honduras. The widespread adoption of the QSMAS by more than 6,000 farmer households in 7,000 ha, has been driven by a two-fold increase in crop yields (maize from 1200 to 2500 kg/ha, beans from 325 to 800 kg/ha) and cattle stocking rates, and significant reduction in costs associated with agrochemicals and labor, in comparison to the traditional slash and burn system.

The QSMAS is based on planting annual crops in an improved (through practices adapted by technicians and farmers) indigenous slash and mulch management system. It starts with the selection of a well developed (high amount and diverstity of trees and shrubs) fallow. Then, "pioneer" crops sorghum (*Sorghum vulgare*) or common beans (*Phaseolus vulgaris*), whose seedlings are capable of emerging through the mulch, are sown by broadcast. Maize (*Zea mays*) is not sown as a pioneer crop because of too much quantity of mulch that affects the emergence of seedlings and also because of the late season planting (August) that does not provide adequate soil moisture for grain filling late in the season. After planting, selective and partial slashing and pruning of dispersed trees and shrubs in fallows (naturally regenerated secondary forests) is done, followed by the removal of the firewood and trunks and the uniform distribution of the biomass (leaves and fine shoots) that results as mulch. The outcome is a plot with numerous slashed trees, nonslashed high-value multipurpose timber and fruit trees, and slashed shrubs (that are used for production practices such as holding harvested bean plants to avoid infection of bean pods), and a dense layer of mulch. After the pioneer crop, for about 10 years as the recognized system's productive life based on the regrowth potential of trees in the system, QSMAS practices include the annual production of maize as main crop intercropped with beans or sorghum using zero-tillage, the continuous slashing and mainly pruning of trees and shrubs in order to eliminate branches (to take out for firewood) and regrowth (to avoid shade for the crops), a continuous mulching (from litterfall, slashing of trees and application of crop residues), spot fertilization technologies, and sometimes the use of preemergence herbicides.

The main gains of the QSMAS in productive terms are improved incomes, less labor for land preparation and weed control, reduced costs of production, and higher net profits. Farmers perceive the following main advantages of the system: (i) the higher soil water holding capacity when rainfall is erratic (irregular or insufficient due); (ii) reduced soil erosion; (iii) the improved resilience of the system at landscape level from natural disasters such as hurricane Mitch; (iv) improved soil fertility due to efficient recycling of nutrients through plant residues; and (v) the continual supply of firewood.

A special project funded by WFCP (Water & Food Challenge Program) is being executed by CIAT in collaboration with partners in Honduras and Nicaragua. The main objective of the project is to determine the key principles behind the social acceptance and biophysical resilience of QSMAS by defining the role of the management components of the system and QSMAS' capacity to sustain crop production and alleviate water deficits on steeper slopes with high risk of soil erosion. Studies are focused on quantifying water dynamics, nutrient dynamics, and greenhouse gas fluxes and also validation of the system in dry areas of Nicaragua. This report includes results from field studies in Honduras on biophysical characterization of the fallow system before converting to QSMAS, the effect of proportion of stones (under greenhouse conditions) on soil water-holding capacity and crop biomass production, the effects of rainfall through simulated rain on soil erosion processes, the baseline results for N-mineralization and P-frctionation from QSMAS plots of different ages, and the preliminary trends on greenhouse gas fluxes. Preliminary results are also reported from the characterization of the QSMAS plots where the system is being validated in Nicaragua.

In Honduras, the study area is located in the municipality of Candelaria (14°4'60" N, 88°34'0" W), within the Lempa river upper watersheds in the department of Lempira. The regions' life zone (Holdridge) is a sub-humid tropical semi-deciduous forest and pine tress, while its climatic classification (Köppen) is a Tropic Humid-Dry (Aw) region with an annual (bimodal) rainfall. Mean annual precipitation is about 1400 mm falling mainly from early May to late October, with a distinct dry season of up to six months (November-April). During the dry season strong winds blow from the North and the enhanced evapotranspiration rates cause severe water deficits (over 200 mm) until the onset of rains. Temperature ranges between 17-25 °C. Soils are steep (from 5% up to 50% slope) between 200-900 masl, classified as stony Entisols (Lithic Ustorthents) influenced by volcanic ashes associated with igneus and intrusive rocks, usually with low labile P and soil organic matter contents (2.8-3.9 %) and pH between 4.1-6.2. Agriculture is strongly concentrated around small farms (80% with less than 5 ha).

In Honduras, field plots (200 m^2) were established in April 2005 for the comparison of 5 treatments: QSMAS of different ages (0-2 years, 5-7 years and 10+ years old), the traditional Slash & Burn (SB) production system, and the natural fallow (as baseline). The four treatments including production systems were split in order to apply a fertilizer treatment (with fertilizer or without fertilizer application). Each treatment was replicated in 3 different farms. In Nicaragua, plots for the QSMAS validation were established in May 2005. QSMAS will be compared with three treatments: SB system (traditional), crop residue management, and natural fallow (reference system), in plots of 900 m^2 per treatment. Each set of treatments was replicated in 6 different farms.

The analysis of the information generated would allow us to understand the biophysical changes of the QSMAS across the time, to compare the relative advantages of its implementation in comparison with the SB system, and the magnitude of changes in the system compared to the natural fallow.

Determination of soil losses in Quesungual Slash and Mulch Agroforestry System (QSMAS)

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The farmers practicing the Quesungual Slash and Mulch Agroforestry System (QSMAS) relate the superior performance of QSMAS with reduced soil losses compared with the traditional slash and burn

(SB) system. Previous research conducted by Michelle Deugd between 1998 to 2000 indicated 93% reduction in soil loss in QSMAS compared with the SB system. Deugd also found that the main factor for reduced soil loss in QSMAS was not the slope but the soil cover from the mulch, the tree density and the combined effect of diversified root systems. The main objective of the present study was to monitor soil losses in QSMAS of different ages (>2 years, 5-7 years, >10 years) in comparison with the SB system and also the natural fallow system before converting to QSMAS.

Plots to estimate soil losses were established in each of the 5 treatments (QSMAS of >2 years, 5-7 years, >10 years, SB, and fallow) by inserting aluminum sheets to collect the runoff (using some of the technologies of USLE) from 5 m long and 1.5 m wide (7.5 m^2) plots located in the middle of the slope of each treatment. At the base of the each plot a soil trench was prepared across the plot width and lined with black plastic sheet to collect runoff and the soil eroded from the plot. The samples of runoff and soil were collected at weekly intervals for 22 weeks. Rainfall distribution during the rainy season was recorded from May to October of 2005. The samples collected were dried in the oven at 105 ∀C for 24 h to quantify soil losses.

Highly significant (*P*<0.0001) differences were observed in soil losses from different systems tested during the evaluation period (Figure 31). The amount of soil loss varied between 2.2 to 41.3 t ha^{-1}. The system with lowest amount of soil loss was the fallow with the natural vegetation. As expected, the extent of soil loss was the highest with the traditional SB system. When soil losses among the QSMAS systems of different ages were compared, QSMAS of 5-7 years age showed higher soil losses than the other two QSMAS systems.

Rate of eroded soil per unit of rainfall showed similar tendency (SB>QSMAS>Fallow) to the results on soil losses (Figure 32). Fallow system had the lowest values of eroded soil per unit amount of rainfall.

Results on the dynamics of soil loss indicated that the extent of erosion was greater during the first month of the rainy season (Figure 33). The traditional SB system showed markedly higher amounts of soil loss over time compared with the other systems, while the QSMAS over ten years (Q>10) and the fallow system showed lower values over time.

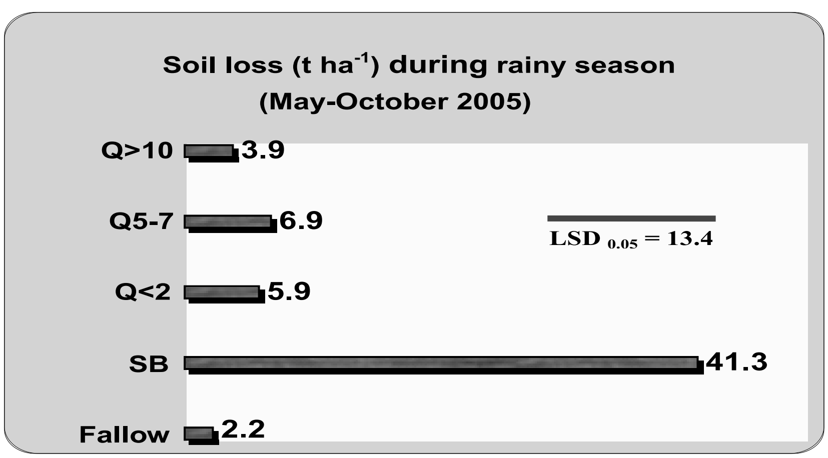

Figure 31. Differences in soil losses (t ha^{-1}) during 22 weeks from QSMAS plots of different ages (Q<2, Q5-7 and Q>10 years) compared with slash and burn (SB) and fallow systems.

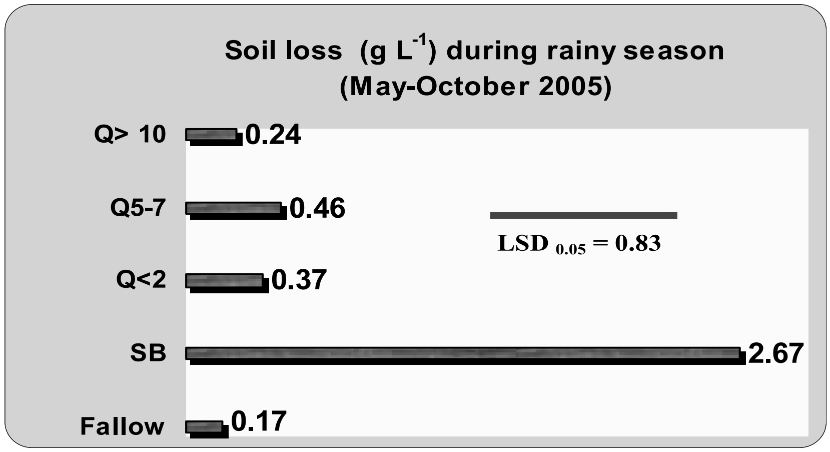

Figure 32. Differences in eroded soil per each litter of rainfall (g l^{-1}) during 22 weeks from QSMAS plots of different ages (Q<2, Q5-7 and Q>10 years) compared with slash and burn (SB) and fallow systems.

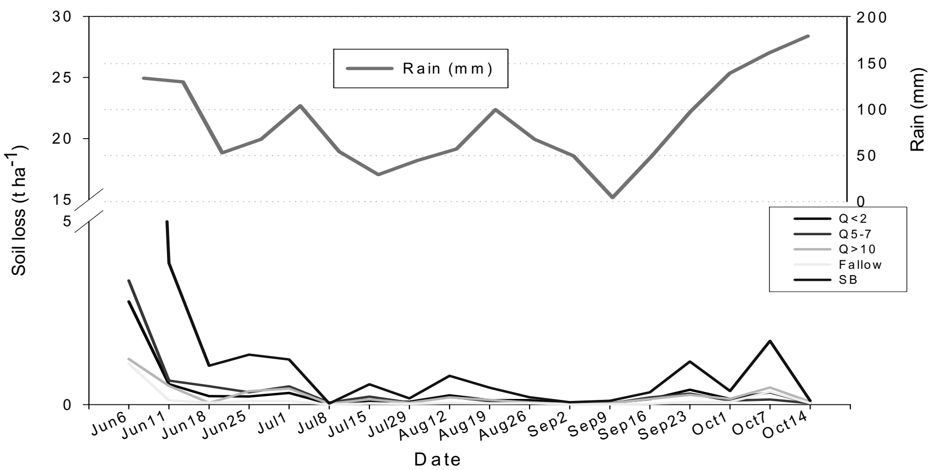

Figure 33. Dynamics of soil losss (t ha^{-1}) during June to October 2005 from QSMAS plots of different ages (Q<2, Q5-7 and Q>10 years) compared with slash and burn (SB) and fallow systems.

Effects of different proportions of stones in soil and frequencies of water application in the production of biomass of maize under greenhouse conditions using soil from hillsides

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It is widely accepted that stony soils are difficult for cultivation and a higher proportion of stones in soil restrict root growth and crop productivity. The Quesungual slash mulch agroforestry system practiced on Entisols in the hillside region of southern Lempira (Honduras) improves the food security through maize and beans in the long dry season due to improved conservation of soil moisture and nutrients and reduced erosion. These soils have significant proportion of stones (up to 40% of the soil volume). To understand the effects of the proportion of stones in retaining the soil moisture and influencing maize production, a greenhouse experiment was conducted at CIAT-Palmira, Colombia.

Maize was sown in a fine soil fraction of an Entisol mixed homogeneously with five proportions of stones (0, 20, 40, 60 and 80% of soil volume) and tested with three frequencies of water application (24, 48 and 120 hours), replicated three times, in a split plot design. Deionized water was supplied in a quantity of 0.3 liter per pot each time. Water supply simulated periods of maximum (September), medium (May) and minimum (November) precipitation months during the middle of the rainy season, early rainy season and end of the rainy season, respectively in the hillside region of Lempira, Honduras.

To conduct the greenhouse experiment, soil with stones were sampled at 0-20 cm soil depth, in a steep slope of the hillsides in Suárez, Cauca department, Colombia. Soil samples were air dried, sieved with 2 mm mesh to separate fine soil fraction from stones. We evaluated the bulk density of fine and heavy (stone) fractions, moisture retention capacity of fine and heavy fractions as well as soil chemical conditions of the fine fraction. Two maize seeds of the Pioneer hybrid P30F80 were sown in 5 liter pots to evaluate plant height, leaf number, and stem diameter for 6 weeks at weekly intervals and, at harvest time, shoot biomass, root biomass, root length, mean root diameter, shoot nutrient (N, P and K) uptake as well as total nutrients in soil and in leached soil solution. Gravimetric soil moisture content was determined daily. Nutrients were supplied at ten days after planting at adequate levels to optimize the production of dry matter. The root measurements were made with an STD-1600 EPSON scanner and the images were analyzed with the WinRhizo v.4.0b software (Regent Intruments Inc., Quebec, Canada).

Stone proportion in the soil collected from Cauca was 40% of the soil volume. Soil chemical conditions of fine fraction were: pH (1:1, soil:H_2O) 4.51, P (Bray 2) 9.1 mg kg^{-1}, K ($cmol_c$ kg^{-1}) 0.26, Ca ($cmol_c$ kg^{-1}) 2.33, Mg ($cmol_c$ kg^{-1}) 0.70, CIC ($cmol_c$ kg^{-1}) 16.9, SOM (1%) and Al saturation (62%). Bulk density values of fine (soil) and heavy (stones) fractions were 1.0 and 2.3 g cm^{-3}, respectively, and mean diameter of stones in the heavy fraction was 3 cm.

Highly significant differences ($P<0.0001$) were observed within stone volumes and within water application frequency for soil moisture content, total biomass (shoot + root) production, root biomass, root length and mean root diameter.

Total biomass production. Total biomass (shoot + root) production varied from 16.9 g pot^{-1} with 0% stone volume and 24 h water application frequency to 5.0 g pot^{-1} with 20% stones and 120 h of water application frequency (Table 23). Total biomass decreased with longer time of water application frequency. Stone volume in soil affected total biomass production and a marked reduction in total biomass was observed with 80% volume of the stones with 24 and 48 h of water application intervals. When the water application frequency was 120 h, 40 and 60% of stone volume in soil increased the total biomass production up to 54% with respect to 0 and 20% of stone volume (Table 23, Figure 34).

Shoot biomass production. Shoot biomass production of maize ranged from 15.0 g pot^{-1} for 0% stone and 24 h water application frequency to 4.2 g pot^{-1} with 20% stone volume and with water application frequency of 120 h. The higher values of shoot biomass production appeared with 0% stone volume and frequencies of water application of 24 and 48 h. The lowest values of shoot biomass production were observed with 0 and 20% of stone volume and with an irrigation frequency of 120 h. For the frequency of water application of 120 h the highest production was obtained with 60% stone volume (44% higher than that of 0% stone volume). There was a decreasing shoot biomass production with an increasing stone volume in the soil when the time of irrigation frequency was shorter (24 and 48 h), but it was the contrary when this frequency was longer (120 h, Figure 34). The differences in these results could be due to a greater leaching of mobile nutrients (N, K) in the system with more frequent water application (24 and 48 h). Additionally, less evaporation from the system with higher stone volume (data not shown) might have contributed to the superior performance of maize with 40 and 60% of stone volume with 120 h of water application frequency.

Table 23. Effects of different stone proportions mixed with fine fraction of soil (<2 mm) and three water application frequencies on total biomass (shoot + root) production of maize.

Stone volume (%)	Total dry matter (g pot^{-1}) Irrigation frequency (h)			$LSD_{0.05}$
	24	48	120	
0	16.9	16.4	5.8	3.20
20	16.7	14.1	5.0	0.90
40	16.3	15.3	8.1	2.35
60	16.7	13.1	8.6	2.35
80	8.9	8.6	6.9	-
$LSD_{0.05}$	3.49	2.19	1.24	

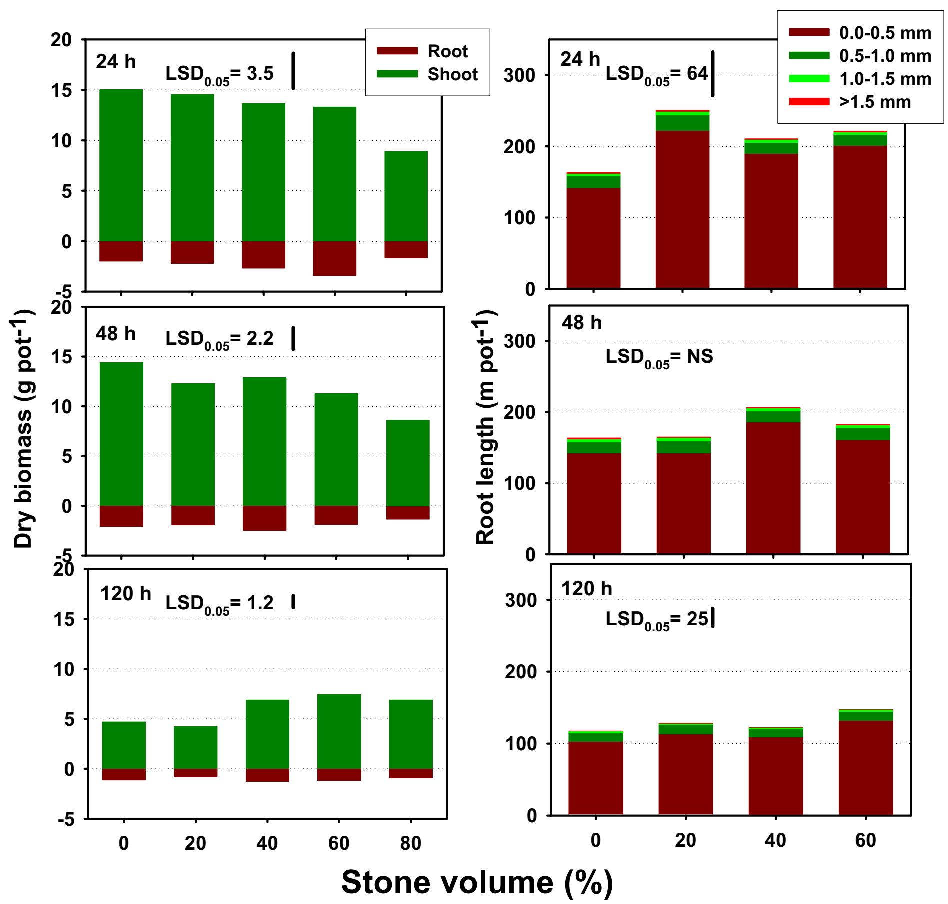

Figure 34. Production of shoot biomass, root biomass (g pot^{-1}) and root length (m pot^{-1}) in maize plants grown in an Entisol from hillsides of Cauca, Colombia, with 5 stone proportions and 3 water application frequencies.

Root biomass production. Maize root biomass changed between 3.47 and 0.81 g pot^{-1} for 60% stone volume – 24 h irrigation frequency and 20% stone – 120 h irrigation frequency, respectively (Table 24, Figure 34). Similar to changes in shoot biomass, root biomass diminished with longer frequency of water application (120 h). The lowest values of production of root biomass were observed in all stone volumes with the irrigation frequency of 120 h. Under more frequent water application (24 h), root biomass increased with stone volume of upto 60% in soil. Under intermediate frequency of water application (48 h), root biomass increased up to 40% stone volume. Low frequency of water application did not affect root biomass production.

Frequency of water application affected root length (Figure 34). More frequent water application (24 h) markedly improved total root length per pot and higher value of total root length was observed at 20% of stone volume. Intermediate frequency of water application (48 h) produced higher value of total root length with 40% of stone volume. Low frequency of water application produced higher value of total root length with 60% of stone volume. These results indicate that with less frequent rains, the higher proportion of stone volume (up to 60%) can improve root development through increased soil moisture (results not shown). Higher values of root length were observed with low stone volume (20%) in the soil with more frequent water application (24 h). The main effects on total root length were observed with fine roots in all treatments.

Shoot nutrient content and shoot nutrient uptake. Table 25 shows shoot nitrogen (N), phosphorus (P) and potassium (K) content and uptake. N content ranged from 24.2 to 10.8 g kg^{-1}, for 0% stone – 120 h water application frequency to 60% of stone – 24 h water application frequency. It decreased with more stones until 60% volume to all water application frequencies (24, 48 and 120 h) and it decreased too with less time intervals of water supply possibly due to more leaching from the system plant-soil. Shoot N uptake changed from 272 to 86 mg pot^{-1}, for 0% stone – 48 h water application interval to 80% stone – 24 h water application interval. Greater shoot N uptake was observed with intermediate water application frequency (48 h) while it was decreased with higher stone proportion in soil. The higher frequency of water application (24 h) resulted in lower values of shoot N uptake and at this frequency of water application shoot N uptake diminished with increasing stone volume in soil.

Shoot P content ranged from 1.75 g kg^{-1} for 0% stone – 48 h water application frequency to 1.30 g kg^{-1} for 20% stone – 24 h water application frequency. The water application frequency of 48 h showed higher shoot P contents while the soil without and with 40% of stone volume presented the highest values (Table 25). With 24 h and 120 h of water application frequencies maximum values were found with 80% stone volume (1.72 g kg^{-1}) and 60% stone volume (1.62 g kg^{-1}), respectively (Table 25). Shoot P uptake changed between 25.0 and 5.6 mg pot^{-1} for 0% stone – 48 h water application frequency and 20% stone – 120 h water application frequency, respectively. Shoot P uptake diminished with increasing stone volume in soil at 24 h and 48 h water application frequencies, while with the water application frequency of 120 h these values increased with increasing stone volume between 20% and 60% in soil.

Maize shoot K content changed between 51.7 and 29.0 g kg^{-1} for 0% stone – 120 h water application frequency and 20% stone – 24 h water application frequency, respectively. The content of both K and N in shoot tissue increased with the decrease in water application frequency with all proportions of stone (Table 25). Shoot K uptake, ranged between 503 and 167 mg pot^{-1} for 0% stone – 48 h water application frequency and 20% stone – 120 h water application frequency, respectively. The lower values of shoot K uptake corresponded to 80% stone proportion with water application frequencies of 24 h and 48 h, while with the water application frequency of 120 h it happened with 20% stone proportion (Table 25).

Table 24. Effect of different stone volume mixed with fine fraction of soil (<2 mm) and three irrigation frequencies on root biomass production of maize.

Stone volume (%)	Root dry matter (g pot^{-1})			$LSD_{0.05}$
	Irrigation frequency (h)			
	24	48	120	
0	1.98	2.09	1.13	0.52
20	2.21	1.91	0.81	0.25
40	2.69	2.47	1.27	0.20
60	3.47	1.89	1.18	2.35
80	1.66	1.36	0.91	0.30
$LSD_{0.05}$	0.80	0.50	0.30	

Table 25. Effects of different stone proportions mixed with fine fraction of soil (<2 mm), and three frequencies of water application on shoot N, P and K contents (g kg^{-1} of dry matter) and shoot N, P and K uptake (mg pot^{-1}). Shoot nutrient content values are shown in parentheses.

Nutrient	Stone volume (%)	Shoot content (g kg^{-1}) and shoot uptake (mg pot^{-1})			$LSD_{0.05}$
		Irrigation frequency (h)			
		24 h	48 h	120 h	
Nitrogen (N)	0	(13.6) 204	(18.8) 272	(24.2) 129	56.9
	20	(11.8) 173	(15.0) 186	(19.9) 89	51.1
	40	(11.4) 156	(13.8) 178	(18.2) 125	-
	60	(10.8) 145	(12.0) 135	(16.3) 121	17.4
	80	(11.7) 86	(13.1) 94	(17.2) 103	-
	$LSD_{0.05}$	35.0	43.1	31.7	
Phosphorus (P)	0	(1.46) 22	(1.75) 25	(1.35) 6.3	9.28
	20	(1.30) 19	(1.64) 20	(1.32) 5.6	8.34
	40	(1.44) 20	(1.65) 21	(1.44) 10.0	3.16
	60	(1.47) 20	(1.47) 17	(1.62) 12.1	3.12
	80	(1.72) 13	(1.61) 12	(1.33) 8.0	3.21
	$LSD_{0.05}$	6.16	5.83	3.09	
Potassium (K)	0	(33.4) 499	(34.9) 503	(51.7) 244	116.3
	20	(29.0) 422	(32.7) 402	(39.6) 167	98.2
	40	(32.6) 445	(35.8) 461	(49.5) 342	77.7
	60	(32.3) 430	(33.6) 379	(38.9) 289	77.6
	80	(32.6) 237	(35.1) 253	(42.6) 255	-
	$LSD_{0.05}$	190.0	113.5	61.3	

Values in parentheses are nutrient content (g kg^{-1}).

In summary, both stone proportions in soil as well as water application frequencies affected shoot and root biomass production in maize. Results from this greenhouse study indicated that soil with stone proportion of up to 60% do not restrict total biomass (shoot + root) production of maize with high and intermediate frequency of water application. However, it is important to note that the presence of stones between 40 to 60% volume of soil can markedly improve soil moisture retention and therefore improve maize plant growth under low frequency of water application that simulates drought conditions. The differences in plant growth under low frequency of water application were associated with reduced uptake of nutrients. The presence of stones in the soil is one of the factors improving the performance of Quesungual during the dry season.

Soil physical characterization for determining water dynamics in Quesungual Slash and Mulch Agroforestry System (QSMAS): Establishing the baseline at time zero

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Since 1990, the Quesungual slash mulch agroforestry system (QSMAS) has been considered as fundamental for improving livelihoods of poor farmers of Southern Lempira region of Honduras. The QSMAS system is an alternative to tradicional slash and burn agricultural system. The farmers that adopted the system recognize the major advantage of QSMAS is in its capacity to retain greater amounts of soil moisture during the dry season that improves their food security compared with the tradicional system. Other benefits from QSMAS include: sustainable management of native vegetation and forest, improved quality and availability of water, improved soil fertility and crop productivity, and improved local capacity for reversing land degradation and promoting and disseminating natural resource management innovations.

One fundamental part of understanding the principles behind the functioning of QSMAS is to monitor the biophysical changes over time in the system after its initial establishment. During the establishment of QSMAS, the farmers select a fallow (natural regeneration of the vegetation) with an age of 6 to 12 years during which the tree trunks grow over 10 cm and shrubs grow over 1 m tall. The farmers consider that during this time the soil improves its fertility and timber/firewood is produced from trees and shrubs. They do this one year before establishing QSMAS.

The study area for determining water dynamics in QSMAS is the muncipality of Candelaria in southern Lempira, Honduras. For initial characterization of soil water dynamics in QSMAS, we selected fallows in farms of Juan Mejia in Obrajito community (Fallow 1), and Miguel Cruz (Fallow 2) and Lindolfo Arias (Fallow 3) in the Camapara community and these farms are located betweem 431 and 491 masl. These farms had 10 years of fallow and this fallow was converted to QSMAS and measurements were made before converting to QSMAS. Under field conditions, slope, stone proportion, penetration resistance and soil strength were determined. Soil samples were taken from the profile pits of 50x50x40 cm. Soil samples by depth were collected to determine texture, organic matter content, sand distribution and stability and size of aggregates. Undisturbed soil cores were taken to determine bulk density, saturated hydraulic conductivity, porosity, and soil moisture retention. Based on these measurements, available soil water was calculated.

We determined compacted soil layers by measuring soil strength across soil profile. Results showed in Figure 35 indicate the degree of root growth limitation across soil profile based on soil strength measurements. The values for soil strength varied between 50.0 and 132.7 kPa. The higher values of soil strength that limit root growth and distribution were observed with Fallow 1 and those values were from 10 to 40 cm of soil depth. The middle part of the slope (medium) exhibited less limitation to root growth in both Fallow 1 and Fallow 2. The lower part of the slope of Fallow 1 showed the highest values of root growth restriction in subsoil. The bulk density values varied between 0.95 and 1.26 g cm^{-3} and in general, Fallow 2 showed lower values while Fallow 3 showed higher values except in the top soil layer.

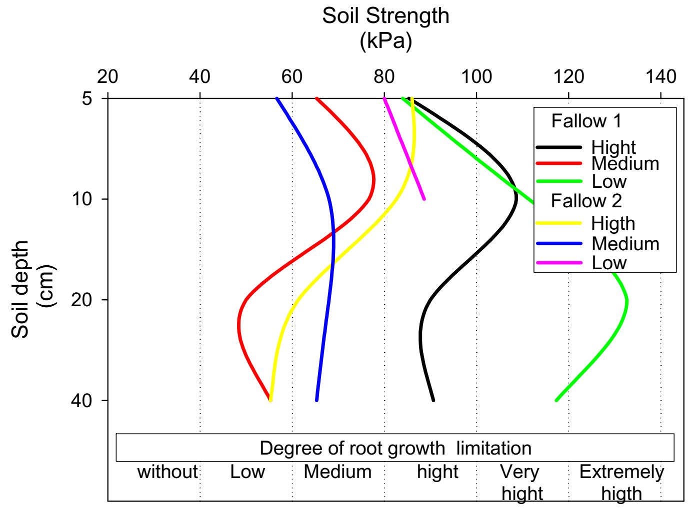

Figure 35. Differences in soil strength (kPa) across the soil profile in the high, médium and low parts of the slope of the Fallow 1 and Fallow 2 farms before establishing the QSMAS.

Bulk density values were not significantly affected across soil depth among the three fallows (Table 26). The total porosity values varied between 51 and 62% and Fallow 2 showed higher values of porosity consistent with lower values of bulk density. Lower values of porosity were observed with Fallow 3 except in top soil layer. The macroporosity values varied between 15.9 and 30% and lower values were observed with Fallow 3. The mesopore values were not markedly different among Fallows and the values varied between 8 and 10%. The micropore values varied bettwen 19.3 and 29.7% and higher values were observed with Fallow 2 and lower values with Fallow 1.

The values of soil moisture content varied between 15.9 and 30.1% (data not shown). Fallows 2 and 3 showed higher values. Available water holding capacity varied between 11.1 and 13.0 cm among the three Fallows and these values are equal to 27.7 and 32.7% of deep of soil, respectively (Table 26, Figure 36). The values of sand content varied between 40.8 and 63.3%. The higher values of sand content were observed with Fallow 1 followed by Fallow 3. The values of silt content varied between 19.0 and 24.7% with no marked differences either among Fallows or across soil depths. The clay content varied between 18.4 and 34.4% with higher values for Fallow 2 followed by Fallow 3. Differences in sand size distribution across soil depth for three fallows are shown in Figure 37. The values of sand size between 1 and 0.125 mm of diameter varied between 1.3 and 11.1%. In general, the higher diameter sand particles were lower while the lower size sand particles dominated in all three Fallows and their values varied between 70 and 87.4 %. These were particularly higher in Fallow 2 which could favor greater retention of soil moisture.

Relationships among root biomass distribution, soil bulk density and available water holding capacity across soil depth (0-40 cm) in the three Fallow farms indicated very highly significant positive correlation (r= 0.97; $P<0.01$) between root biomass and available water holding capacity. A highly significant negative correlation (-0.87; $P<0.01$) was observed between soil bulk density and available water holding capacity. Based on the available water holding capacity in the three Fallow farms and with the assumption of 0.5 cm of water consumption by plants per day during the dry season, we estimate that the water available in soil will be adequate for plants of Fallow 1, 2 and 3 for 22, 26 and 25 days, respectively.

Table 26. Differences across soil depth among the three Fallows in root biomass distribution, bulk density, soil moisture at field capacity, soil moisture at wilting point and available water holding capacity before establishing the QSMAS.

Soil depth (cm)	Fallows	Root biomass (kg ha^{-1})	Bulk density (g cm^{-3})	Soil moisture at field capacity (g 100 g^{-1})	Soil moisture at wilting point (g 100 g^{-1})	Available water holding capacity (cm)
0-5	1	532	1.01	29.70	20.32	1.27
	2	2116	0.89	43.92	29.68	1.58
	3	616	0.96	40.64	27.5	1.50
	P<	ns	Ns	0.003	0.005	0.02
5-10	1	582	1.10	26.96	21.20	1.29
	2	3173	0.95	38.88	27.42	1.49
	3	3358	1.15	29.32	25.20	1.43
	P<	ns	ns	0.04	0.05	ns
10-20	1	1131	1.16	26.78	21.28	2.88
	2	5243	1.05	35.18	28.88	3.42
	3	2578	1.25	28.20	27.56	3.31
	P<	ns	ns	0.07	0.05	0.08
20-40	1	2545	1.14	26.02	19.32	5.67
	2	3683	0.99	34.70	24.48	6.58
	3	1866	1.19	22.36	20.78	6.13
	P<	ns	ns	ns	ns	ns

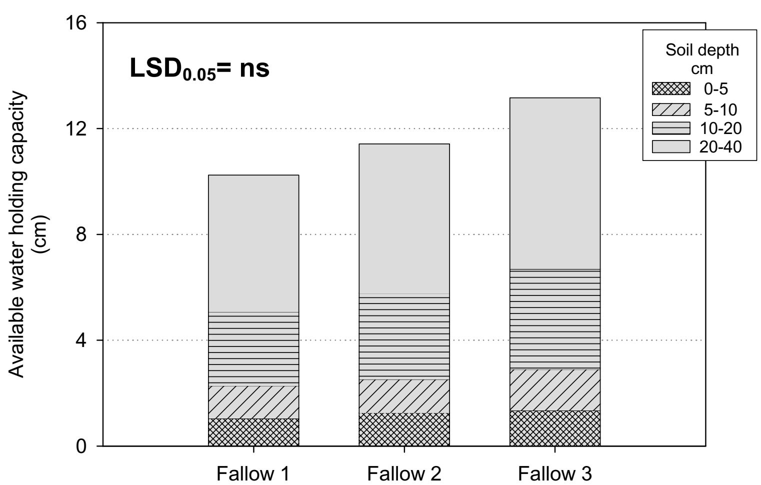

Figure 36. Differences in available water holding capacity at different soil depth among the three Fallow farms before establishing the QSMAS.

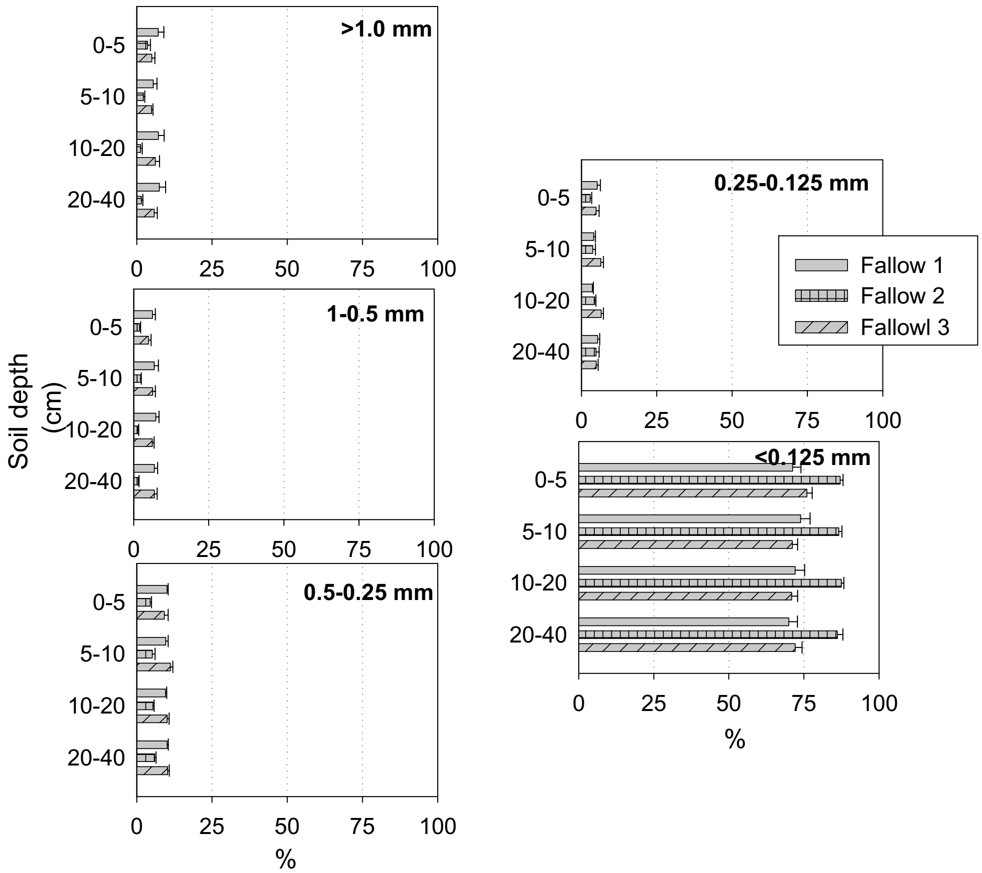

Figure 37. Differences in sand size distribution across soil depth among the three fallows before establishing the QSMAS.

Use of minirainfall simulator to determine runoff, water infiltration and soil erosion in Quesungual Slash and Mulch Agroforestry System (QSMAS) of different ages

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The two main objectives of this study were to determine the impact of the age of Quesungual slash mulch agroforestry system (QSMAS) on: (1) the susceptibility to soil erosion, and (2) the extent of runoff, water infiltration and soil loss. The main tool used to conduct this study was the minirainfall simulator. This helped to evaluate the relationships between soil loss, runoff, water infiltration and soil physical characteristics. The main treatments selected for the study were: QSMAS of <2, 5-7 and >10 years of age, fallow and slash and burn (SB) plots as control. Measurements were made in each treatment using a minirainfall simulator with a rainfall intensity of 80 and 120 mm h^{-1} for 30 min and these intensities are equal to 40 and 60 mm of rainfall. The specifications of the simulated rainfall correspond to rain drops of 2.75 mm diameter with a mass of 9.92 mg and a terminal velocity of 4.04 m s^{-1}. The area of influence for the minirainfall simulator was 0.15 m^2. The runoff was collected with collectors by measuring the volume at every 5 minutes to determine the dynamics of infiltration, rate of infiltration and erosion. Soil erosion was determined by measuring the solids with a subsample of 100 ml that was dried in the oven at 105 ∀C for 24 h.

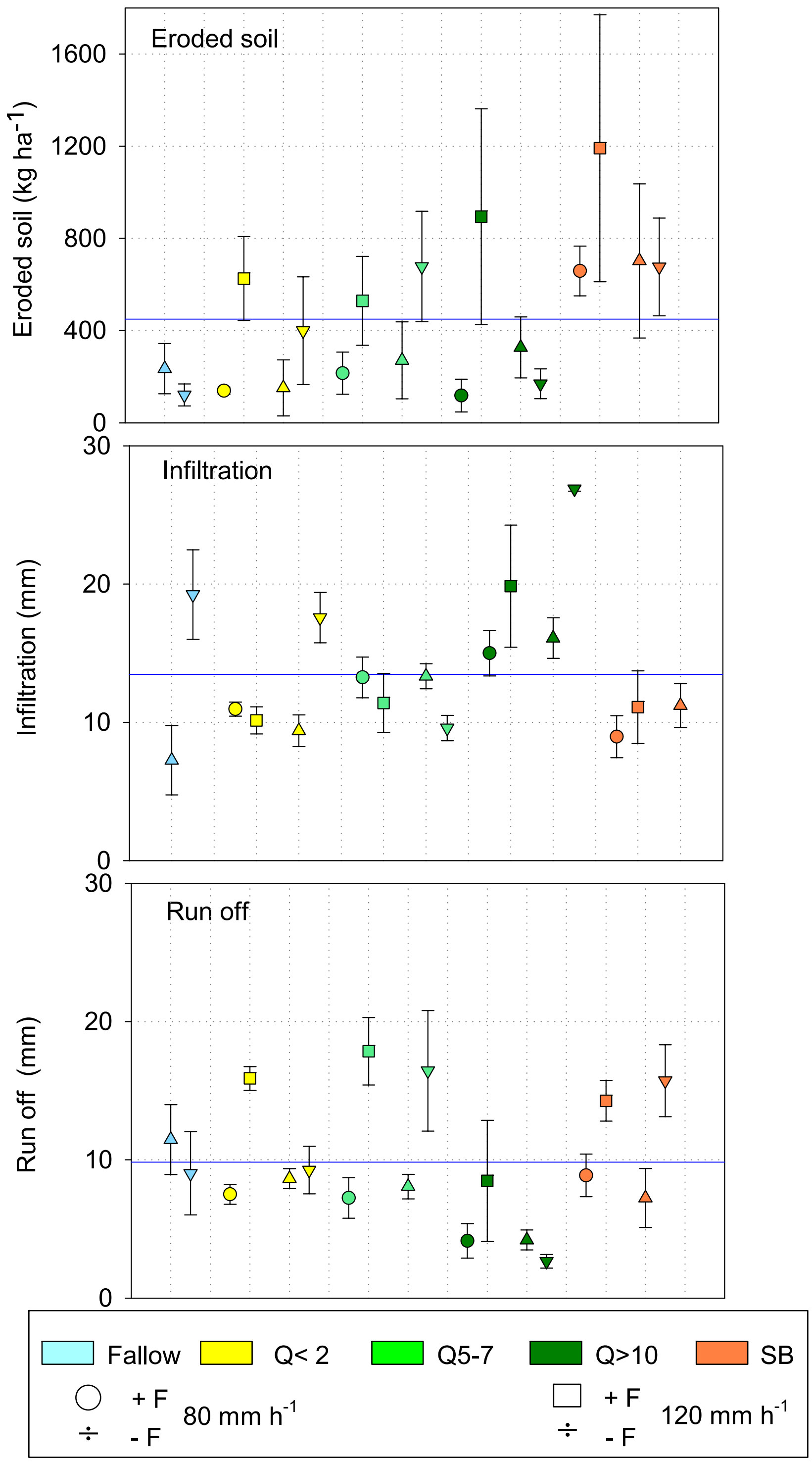

Figure 38. Effect of two levels of rainfall intensity (80 and 120 mm h^{-1}) on soil erosion, water infiltration and runoff in QSMAS of three ages (Q<2, Q5-7, Q>10 years) compared with Fallow and slash and burn (SB) systems under two levels of fertilization (+F; -F).

We observed significant differences among system treatments (*P*<0.01) in terms of eroded soil, runoff and water infiltration (Figure 38 and 39). We observed a positive correlation coefficient of 0.56 between the values of eroded soil and runoff while a negative correlation coefficient of -0.68 was observed between water infiltration and runoff. As expected, soil losses were the highest with the SB treatment followed by >10 year-old QSMAS with fertilizer application and with higher intensity of rainfall (120 mm h^{-1}) (Figure 38). The higher rates of infiltration were observed with >10 year-old Quesungual with no fertilizer application followed by Quesungual <2 and 5-7 years-old without fertilizer application (Figure 38). The lower value for water infiltration was observed with Fallow treatment with low intensity of rainfall. This was due to greater value of soil moisture content observed with this treatment.

The runoff values were lower with the QSMAS >10 yearls-old and this contributed to higher values of water infiltration in this treatment with higher rainfall intensity. The SB treatment and QSMAS 5-7 years-old treatment showed higher values of runoff with high intensity of rainfall under both (with and without) fertilizar application treatments (Figure 39). The Fallows treatment responded differently to the intensity of rainfall with higher infiltration with higher rainfall intensity.

This study indicated that the older QSMAS (>10 years) could minimize soil loss by reducing runoff and improving water infiltration.

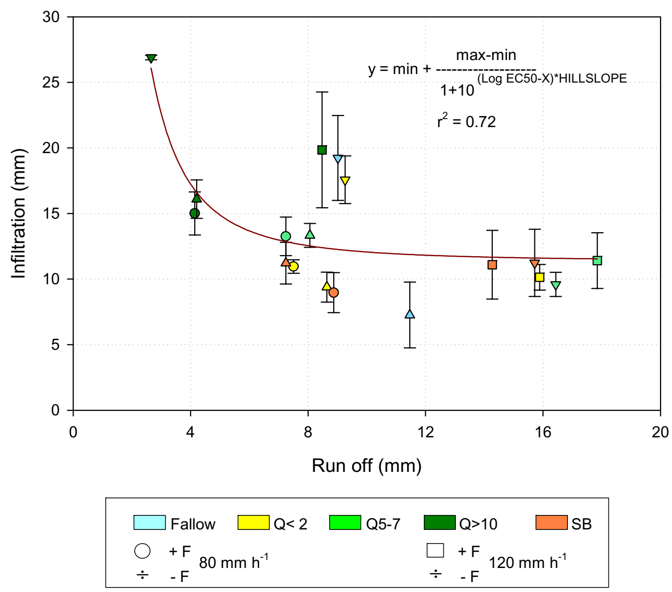

Figure 39. Relationship between runoff and infiltration in QSMAS of three ages (Q<2, Q5-7, Q>10 years) compared with Fallow and slash and burn (SB) systems under two levels of fertilization (+F; -F).

N and P dynamics in Quesungual Slash and Mulch Agroforestry System (QSMAS)

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Determination of nutrient dynamics including transformations across pools and transfer across compartments constitutes one of the major focuses of the Quesugual Project to define the principles contributing to the biophysical resilience of the QSMAS. Since nitrogen (N) and phosphorus (P) are known to be the most limiting nutrients in tropical soils, the main objective of the study on nutrient dynamics is to determine the contribution of the components and practices of the system on the availability of these two key nutrients and the impact of N and P dynamics on the productivity and sustainability of the system. This work reports preliminary results on N-aerobic mineralization and P pools (P-fractionation) in Quesungual system of different ages compared with a traditional fallow system.

The study area is located in Candelaria, department of Lempira, southwest of Honduras. Soil samples were taken from the plots at the end of the dry season (late April – early May 2005), after land preparation for the new cropping year but before the establishment of the crop in rainy season (which defines the sowing moment). Plots were divided into three 3.3 x 10 m as sampling sub-plots, representing the high, medium and low sections of the plot in relation to the slope, to be used as replications within the farms. In every strip 10 sampling points were used, obtaining initially a sample of litter (0.4 m^2 area) without removing the fine organic material adhered to the top soil. Then soil samples from 4 depths (0-2.5 cm, 2.5-5 cm, 5-10 cm and 10-20 cm) were obtained by using 12 cm diameter cylinders. Litter samples were pooled in one paper bag while soil samples were pooled and mixed to obtain ~2 kg (wet wt.) composite soil samples. All samples were air-dried under shade, ground and sieved (2 mm). Analyses were performed in the laboratories of Soil Biology (N mineralization) and Soil Chemistry (P fractionation) of CIAT. Statistical analyses to test the effect of land-use system were carried out by analysis of variance (ANOVA). If the *F*-test was significant ($P<0.05$), the means were compared using Tukey's multiple range test.

Dynamics of potential N mineralization (amonification and nitrification) were determined after different periods (4, 8, 16 and 32 days) of aerobic incubation under laboratory conditions. In general, differences in potential soil mineralization (amonification and nitrification) due to land-use systems were smaller than the observed differences among soil depths. Soil NH_4^+ values showed a marked initial increase up to day 4, with highest values in QSMAS >10 (40 mg N kg^{-1} soil) and lowest for QSMAS 5-7 years (27.2 mg N kg^{-1} soil), followed by a diminishing trend showing largest relative differences among treatments after 8 days of incubation. Thereafter similar values were found in all systems during the rest of the incubation period (Figure 40). In contrast, soil NO_3^- values slowly increased with time so that by day 32 soil NO_3^- values were about two-fold to the initial values. The highest relative difference among treatments was also found after 8 days of incubation suggesting that this could be the optimal incubation period. Total soil inorganic N (NH_4^+ + NO_3^-) followed a similar trend to that of soil NH_4^+, with highest levels for QSMAS 10> years. Potential N mineralization was highest for the top soil layer (0-2.5 cm) and then decreasing with soil depth. Interactions among sources of variation (systems and depth) were not significant. In general, potential N mineralization decreased with time although this pattern was less pronounced or absent with increase in soil depth. This can be due to greater amounts of mulch acumulated on top soil via litter, biomass and crop residues with increasing time under QSMAS >10 years.

For P fractionation, although significant differences were found among treatments (with generally higher values for QSMAS >10) and depths (with values decreasing across depths), no significant interaction was found among those sources of variation (Table 27). In general, QSMAS >10 had higher content of P than fallow probably due to the annual addition of P fertilizers (67 kg ha^{-1}). In the biologically available P pool (labile Resin-Pi and Bic-Pi and readily mineralizable H_2O-Po and Bic-Po fractions), differences were observed among organic fractions, while in the moderately resistant (or moderately labile) P pool (NaOH-Pi and NaOH-Po fractions) differences were in the inorganic fraction, already reported as the main sink of applied P. Clear trends of P accumulation were observed in the residual (not labile Pi and Po) pool, which for being the larger pool (63% of total P, compared to 10% and 27% in biologically and moderately available P, respectively), thus defined the trends observed in total P and toal inorganic P. The Total Po : Total Pi rate reflects the organic composition of the plots, which decreases across years with annual slashes of trees as continuous sources of firewood and its consequent reduction of biomass deposition, starting with values of 2.5 in the regenerated fallow and decreasing in the order to 2.2, 2.1 and 1.5 with QSMAS <2, QSMAS 5-7 and QSMAS >10 years old, respectively.

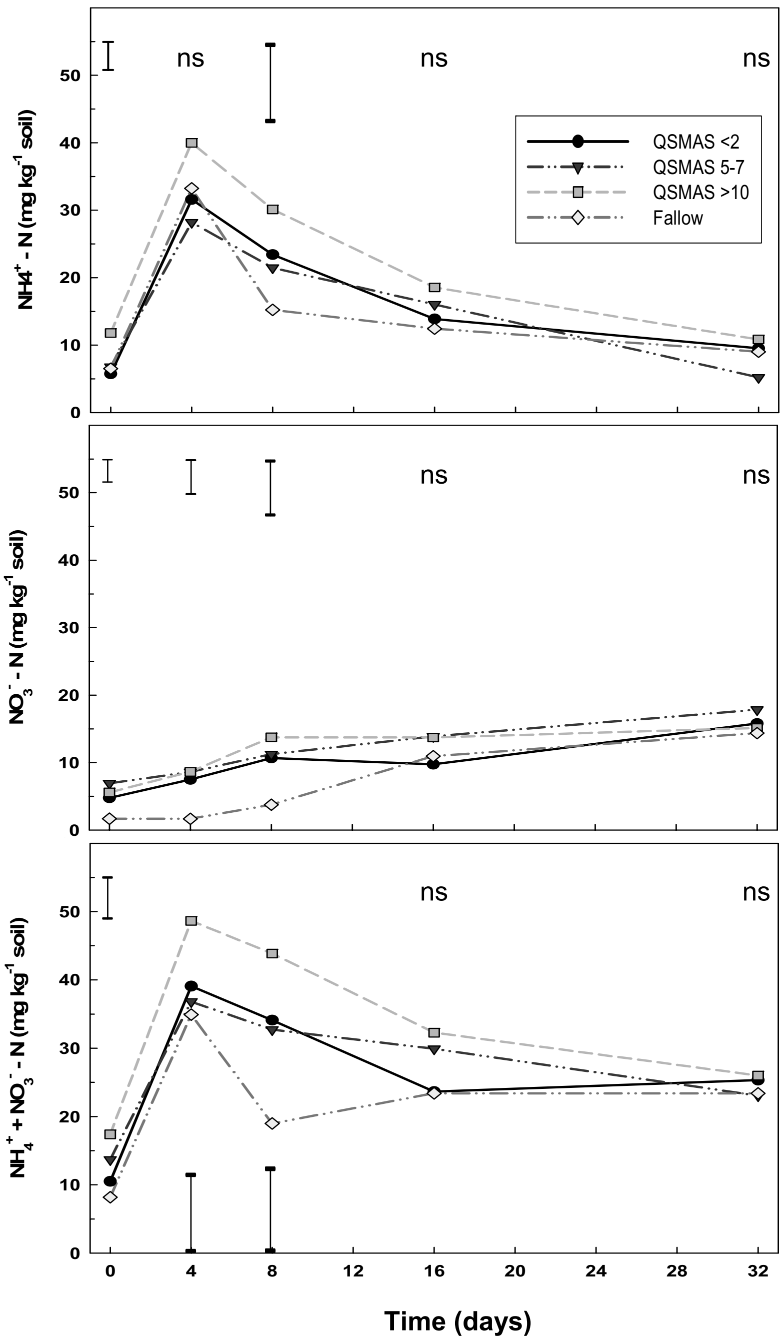

Figure 40. Soil NH_4^+, NO_3^- and total inorganic N during 32 days of incubation of soilsfrom different land-use systems in a hillside agroecosystem of southern Lempira, Honduras. Data are the mean of three replications. Vertical bars indicate $LSD_{0.05}$.

Table 27. Values of soil P in various fractions found at different soil depths of soil collected from different land-use systems in a hillside agroecosystem of southern Lempira, Honduras. Data are the mean of three replications.

Treatment	Resin	H_20	$NaHCO_3$		NaOH		Resid	Sum		
	P*i*	P*o*	P*i*	P*o*	P*i*	P*o*	P*t*	P*t*[‡]	P*i*[†]	P*o*[§]
					mg kg^{-1}					
System										
QSMAS <2	7.7	0.92 a	7.2	8.9 b	12.7 b	51.2	138.2 b	226.7 b	27.5 b	61.0
QSMAS 5-7	6.7	0.33 b	8.6	11.6 a	14.9 b	52.9	170.3 a	265.4 ab	30.2 b	64.9
QSMAS >10	8.4	1.35 a	10.6	9.0 b	28.1 a	59.4	181.6 a	298.5 a	47.1 a	69.8
Fallow	6.3	0.95 a	6.4	9.1 b	13.2 b	54.2	176.7 a	266.9 ab	25.9 b	64.3
F-test	ns	***	ns	**	***	ns	**	**	***	ns
$LSD_{0.05}$	---	0.44	---	2.1	7.5	---	30.4	57.3	16.0	---
Depth (cm)										
0 – 2.5	12.6 a	1.12 a	13.9 a	10.1	23.4 a	67.1 a	188.3 a	316.5 a	49.9 a	78.4 a
2.5 – 5	7.5 b	1.00 ab	9.0 b	10.2	18.4 ab	57.4 ab	173.0 ab	276.5 ab	34.9 b	68.6 ab
5 – 10	5.2 bc	0.80 ab	6.0 bc	9.4	15.2 b	49.7 bc	158.1 ab	244.4 bc	26.5 bc	59.9 bc
10 – 20	3.6 c	0.63 b	3.9 c	8.8	12.0 b	43.6 c	147.5 b	220.0 c	19.5 c	53.0 c
F-test	***	*	***	ns	**	***	**	***	***	***
$LSD_{0.05}$	3.2	0.57	4.2	---	9.3	11.5	31.5	48.9	15.0	12.1
System x Depth	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	44.1	46.5	49.4	20.7	38.1	21.9	16.5	15.3	38.7	19.6

Means within a column followed by the same letter are not significantly different (P=0.05) by Tukey's multiple range test. *F*-test: ***P<0.001, ** P=0.001-0.01, *P=0.01-0.05; ns, not significant.

[†]Sum P*i* = Resin P*i* + $NaHCO_3$ P*i* + NaOH P*i*

[§]Sum P*o* = H_2O P*o* + $NaHCO_3$ P*o* + NaOH P*o*

[‡]Sum P*t* = Resin P*i* + H_2O P*o* + $NaHCO_3$ P*t* + NaOH P*t* + Resid P*t* = Sum P*i* + Sum P*o* + Resid P*t*

After the 2005 sampling to define the baseline for nutrient dynamics, plots including the four production systems (Slash and Burn [SB] and QSMAS of different ages) were split (100 m^2 plots) in order to apply a fertilizer treatment (addition vs. no addition). This would permit to quantify the relative contribution of fertilizer application vs. biomass and crop residue application to the systems' resilience based on productivity and yield stability. Results from the SB system will be reported together next year with data from with and without fertilizer treatments after a 3 year cycle of cropping. Due to the field variability observed *in situ* and also confirmed through the analysis of variance, future analyses will include the use of additional statistical tools that will permit to reduce variability that is inherent to hillside sites. The data presented here will be used as baseline and will be pooled with the data that are being collected during the 3 year cropping cycle to determine the dynamics of both nutrients in the QSMAS compared with the two reference systems (slash and burn, fallow).

N_2O and CH_4 fluxes during conversion from a secondary forest to Quesungual Agroforestry System in southern Lempira, Honduras

O. Ferreira[1], M. Rondón[1], M. P. Hurtado[1] and M. Ayarza[2]
[1]TSBF-CIAT, Cali, Colombia; [2]TSBF-CIAT-Honduras

Fluxes of greenhouse gases (GHG), nitrous oxide (N_2O) and methane (CH_4) were determined in three farms during two years, from the conversion of fallows (secondary forest) to Quesungual Slash and Mulch Agroforestry System (QSMAS) in Candelaria, Lempira, Honduras. The GHG samples were collected at every three weeks during 24 months for three farms (Farm 1: J. Mejía; Farm 2: L. Arias; Farm 3: M. Cruz), from July 2003 to June 2005.

The protocol used for greenhouse gase (GHG) sampling was:

a. *PVC-ring installation in farms:* to determine GHG, the closed chamber technique was used. At the beginning of the study, PVC-rings (diameter 25 cm, height 8 cm) were buried approximately 5 cm in soil. The rings were located in farms following the toposequence and remain in field throughout the study.
b. *Gas sampling:* At the moment of sampling, a PVC chamber was placed (diameter 25 cm, height 10 cm) over the PVC-ring and it's closed hermetically. A syringe with an adapted valve was used to take air samples through the rubber septum located in the top of the chamber, to take an 10 mm air sample in every chamber (at time: 0, 12,5, 25 and 37.5 minutes since chamber installation) and then were injected in glass bottles with vacuum (by freeze drying).
c. *Temperature registry and soil moisture sampling:* temperature inside the chamber was registered in the first chamber of every farm (at time: 0, 12, 5, 25 and 37.5 minutes). A soil sample was taken at a few centimeters of each chamber to determine soil moisture, (soil sample was placed in oven, 24 hours and 105 ºC).
d. *Samples identification:* air sample bottles were identified with a code with the following information: Experiment (Quesungual), Chamber (1 to 4), Farm (1 to 3), time (0, 12, 5, 25 and 37.5 minutes) and sampling date (day/month/year).
e. *Samples processing in laboratory:* Air samples bottles were sent to CIAT laboratory to determinate N_2O and CH_4 concentrations with a Shimadzu GC-14A gas chromatograph with FID (for CH_4) and ECD (for N_2O) detectors.
f. *GHG flows determination:* Finally, N_2O and CH_4 concentrations obtained with chromatograph, temperatures (in ºC) measured in farms, sampling chamber dimensions and gases equation, were processed in a spreadsheet to obtain methane and nitrous oxide net fluxes. Samplings throughout the time were allowed to establish accumulated net GHG fluxes.

The results showed the following: for methane fluxes over time, it was observed that the soil in farms with QSMAS are sinks for methane. There was an increase in CH_4 at the end of the study, especially in Farm 1. Nitrous oxide net fluxes through time presented an irregular behavior. At some moments, farms with QSMAS emited nitrous oxide, and in other times they captured. At the end of the study, greater nitrous oxide emission was observed in the three farms (Figure 41).

Cumulative net methane fluxes were: Farm 1 (-275 mg m^{-2}), Farm 2 (-134 mg m^{-2}) and Farm 3 (-150 mg m^{-2}). Farm 1 presented the smaller values of CH_4emission and Farm 2 the greater values of emission. The three farms were CH_4 sinks. Accumulated net nitrous oxide fluxes were: Farm 1 (78 mg m^{-2}), Farm 2 (143 mg m^{-2}) and Farm 3 (87 mg m^{-2}). Farm 1 presented the smaller N_2O levels and Farm 2 the highest levels. All farms emitted N_2O (Figure 42).

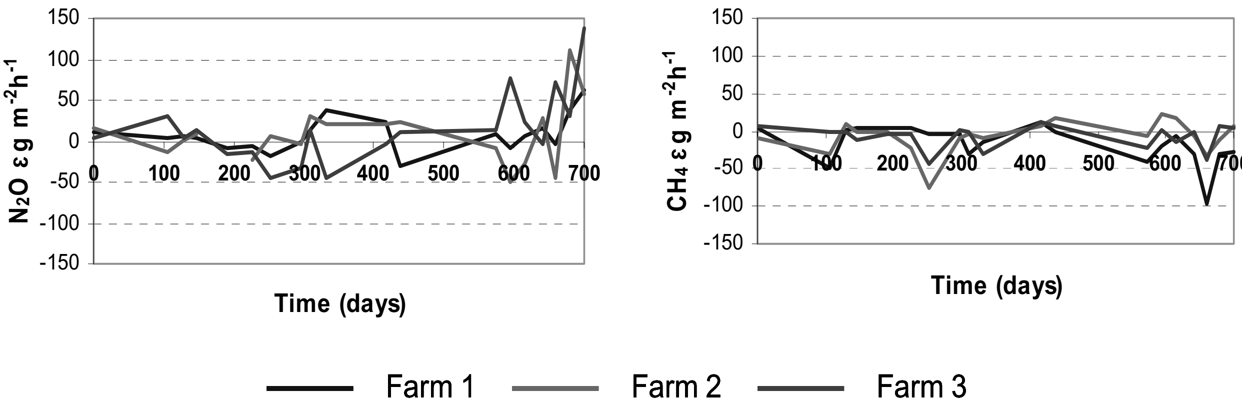

Figure 41. CH_4 and N_2O fluxes over time (July 2003-June 2005) in 3 farms (fallows) converted to QSMAS

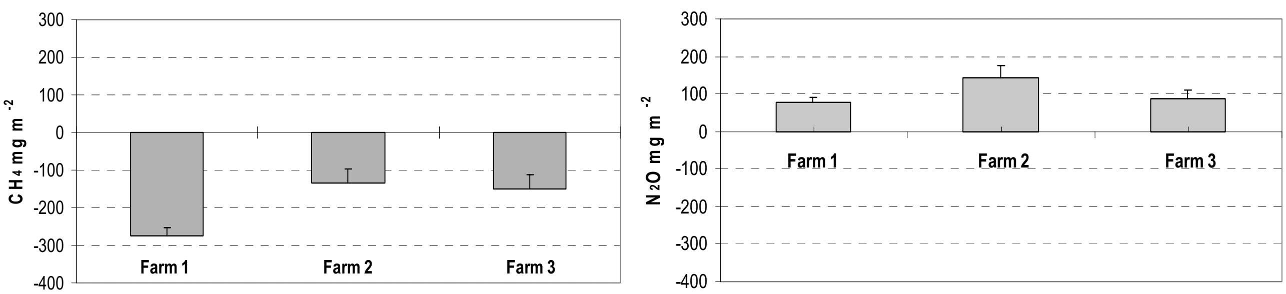

Figure 42. Cumulative CH_4 and N_2O net fluxes (July 2003-June 2005) in 3 farms (fallows) converted to QSMAS.

This work is preliminary and at present GHG fluxes are being monitored in QSMAS plots of different ages and different land use systems to quantify the environmental benefits of QSMAS to mitigate global change.

Firewood use in rural and urban communities in Candelaria, Lempira, Honduras

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[1]*TSBF-CIAT, Cali, Colombi a;* [2]TSBF-CIAT-Honduras

We determinated firewood use in rural communities and neighborhoods in Candelaria, southern Lempira, Honduras. It was done with a semiestructured survey conducted between September and December 2005 with an estimated 7% sampling error. We used a total of 35 surveys that included 25 surveys in 6 rural communities (El Obrajito, Camapara, San Lorenzo, Gualmuraca, Portillo Flor and Quesungual, all them in the QSMAS influence zone) and 10 surveys in 3 Candelaria's neighborhoods (El Centro, San Francisco and Gualcinse). The results showed that more than a half of the houses don't have electric energy (72% in rural area) and firewood consumption by family per week is about 125 firewood sticks (aprox. 50 cm length and 5 cm diameter), equivalent to 3.9 t $year^{-1}$. The prefered trees for firewood are *Cordia alliodora* and *Diphysa american a* while *Cecropia peltata* and *Bursera simarouba* were identified as the less prefered trees. Firewood is generally collected from maize fields by men and children (sons), with an average walking distance of 18 minutes, three times per week and usually taking all day to do this task. 62% of families own a 'hornilla' (simple non-technological stove) and 61% of these were outside of the house. Headache and eye illness were the two most common health problems mentioned in the surveys. Almost 50% would like to change to electric or gas energy and those who wouldn't change mentioned that the main reason for them is that firewood is less expensive. About 48% mentioned that food cooked with firewood tastes better especially due to slow cooking time. It is important to study firewood consumption dynamics in rural and urban areas to be able to mitigate deforestation in many parts of the world, especially in developing countries.

Application of QSMAS principles to drought- prone areas of Nicaragua: characterization of soil chemical and physical properties under traditional and QSMAS validation plots in la Danta watershed in Somotillo

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[1]TSBF-CIAT, Cali, Colombia; [2]TSBF-CIAT, Honduras; [2]INTA, Nicaragua

One of the main expected outputs of the Quesungual Slash and Mulch Agroforestry System (QSMAS) project is to extrapolate the management principles and therefore obtain similar benefits in similar regions of Latin America. The Rio La Danta watershed in Somotillo was chosen to carry out validation activities with active participation of INTA, UNA and farmer groups. The objective of this study was to: (1) characterize changes in soil chemical and physical properties in plots under traditional and QSMAS management systems; (2) evaluate changes in soil quality as influenced by slope, management system and soil properties; and (3) determine the impact of QSMAS on crop production in comparison with the traditional systems.

The work is in progress in the Rio La Danta watershed in Somotillo, Nicaragua (13º 04Nĳ45" N, 85º 47Nj 25" W and 13° 08'39''N, 86° 49'59'' W). Annual precipitation is 700 to 900 mm with a long dry season of up to six months. The mean annual temperature varies from 25 to 34 ∀C. Altitude varies from 200-500 masl. Soils are shallow Inceptisols with a loamy texture. Six farms were selected to plant crops in plots of 900 m^2 using three management systems: (1) QSMAS; (2) residues left on the soils; and (3) traditional slash and burn. A fallow treatment was included in the study as a comparison with the natural system. Crops were planted with a minimum disturbance to the soil. Soil samples were taken at three positions in each plot according to slope (lower, medium and upper part). Samples were taken at four soil depths (0-5, 5-10, 10-20 and 20-40 cm) from 50x50x50 cm soil pits. With undisturbed soil samples, water retention curves were determined to measure hydraulic conductivity, bulk density was determined to measure soil permeability and susceptibility to compaction, and pore size distribution was determined to measure total porosity. With disturbed soil samples, the follwing measurements were made: chemical analysis, texture, real density, aggregate distribution and stability of aggregates (>6, 4, 2 and 1 mm). Maize was planted in each systemI in 2005 and 2006 in order to evaluate production dynamics over time.

Differences in pore size distribution for each treatment at four soil depths are shown in Figure 43. All treatments showed a macroporosity value greater than 50%. Mesoporosity values varied from 18-27% with lower values at 0-10 cm soil depth.

Differences in maize grain yields for 2005 and 2006 are shown in Figure 44. Crop yields were slightly higher in the slash and burn plots in comparison to the QSMAS plots probably due to the nutrient supply from ashes. This effect disappeared in 2006 when crop yields in this treatment decreased by 40% while crop yields in the QSMAS and residues treatment decreased only by 11 and 15% respectively. Further work is in progress.

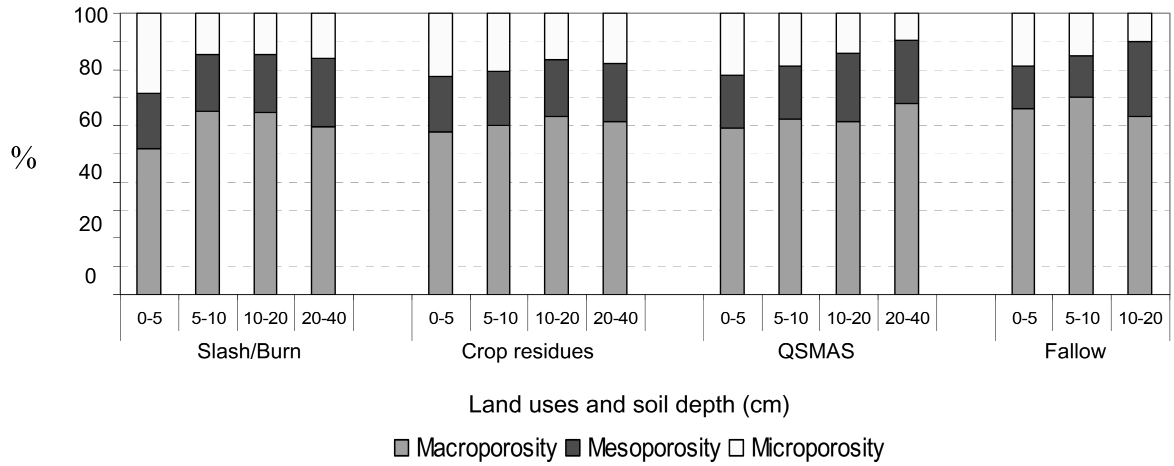

Figure 43. Differences in distribution of macro, meso and micropores among four different systems of land use in Somotillo, Nicaragua.

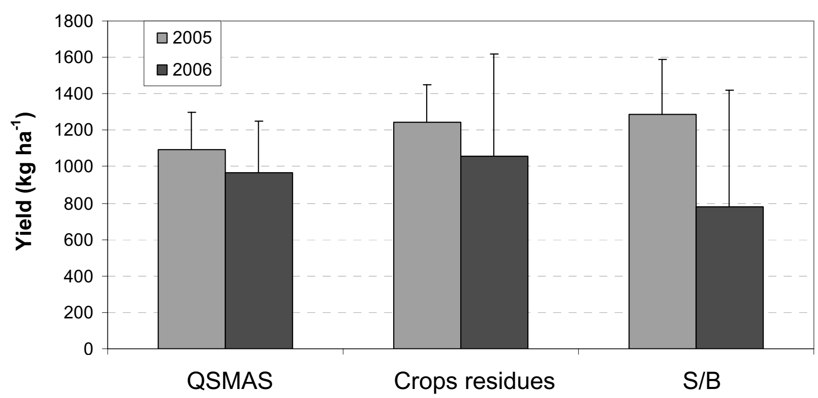

Figure 44. Differences in grain yield of maize during 2005 and 2006 among three different systems of land use in La Danta, Somotillo, Nicaragua.

Output target 2009

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

Published work

Chianu[1], J., Vanlauwe[1], B., Mukalama[1], J., Adesina[2], A. and Sanginga[1], N. (2006) Farmer evaluation of improved soybean varieties being screened in five locations in Kenya: Implications for research and development. African Journal of Agricultural Research 1(5): 143–150.
[1]TSBF-CIAT, Kenya; [2]Rockefeller Foundation, Kenya
Abstract: In order to determine the improved soybean varieties that if recommended to the farmers would have a high probability of adoption, a farmer participatory approach was used to evaluate 12 soybean varieties at full podding in five locations (Oyani, Riana, Kasewe, Akiites, and Mabole) in western Kenya. These comprise of 11 improved varieties (TGx1871-12E, TGx1895-4F, TGx1895-33F, TGx1895-49F, TGX1878-7E, TGx1893-7F, TGx1893-10F, TGx1740-2F, TGx1448-2E, NAMSOY 4m, and MAKSOY 1n) and one local variety (Nyala). Farmers generate all the 17 criteria for use in the evaluation, with researchers only facilitating. One hundred and two farmers (52% females) participated in the evaluation. A scoring matrix was employed to articulate the results. Data analysis was done using Microsoft Excel. This paper shows that of the seven dual-purpose varieties tested in all the five locations, only TGx1740-2F was acceptable in all. Some varieties were acceptable in specific locations: TGx1895-49F in Oyani, Nyala in Kasewe, TGx1448-2E in Akiites, and TGx1893-7F in Mabole. This result shows that to avoid low adoption, a blanket recommendation of varieties that were accepted only in selected locations must be avoided. TGx1740-2F was the only variety that could be recommended across locations and that was clearly better than the existing farmers' own variety, Nyala.

Work in Progress

Evaluation of the farmers' use of organic and inorganic nutrient in the farming systems of Kenya and Uganda and the relationship with market access

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[1]TSBF-CIAT, Kenya; [2]University of Ibadan, Nigeria; [3]NARO, Uganda; [4]Dominion Farms, Siaya District, Kenya; [5]Rockefeller Foundation, Kenya
Organic and inorganic nutrients are critical for agricultural factor productivity in the farming systems of Kenya and Uganda. There is a general feeling that the use of organic and inorganic nutrients by farmers bears some relationship with their access to market for inputs and outputs. However, this relationship is not yet fully understood. Various schools of thought hold different views regarding how access to market affects the use of organic and inorganic fertilizers and how different typologies (rich vs. poor farmers, male-headed vs. female-headed farm households, old farmers vs. young farmers, farmers with secure land tenure vs. farmers with insecure land tenure, etc.). In addition to this, some people simply belief that farmers who are able to sell their farm output automatically invest part of the proceeds on the purchase of organic and inorganic fertilizers.

The objectives of this study are: (1) to evaluate the use of organic and inorganic fertilizers in the farming systems of Kenya and Uganda, (2) to establish the relationship farmers' access to market (input and output) and their use of organic and inorganic fertilizers, (3) to evaluate how access to market influences the behavior of different typologies of farmers towards the use or organic and inorganic fertilizers, and (4) make recommendations on how to improve the use of organic and inorganic fertilizers by different typologies of farmers in Kenya and Uganda and similar environments.

This study was carried out in selected districts in Kenya and Uganda. Data for the attainment of the objective of this study were collected from randomly selected farm households that include those that fall into the different typologies (rich vs. poor farmers, male-headed vs. female-headed farm households, old farmers vs. young farmers, farmers with secure land tenure vs. farmers with insecure land tenure, etc.) of interest and from two broad market access (poor market access vs. good market access) categories. This primary data are being complemented with data from secondary sources (reports, published articles, books, etc.) and key informant interviews. Data processing using Microsoft Excel and SPSS is in progress.

Data collection for the Uganda arm of the study was just completed. Data processing (validation and cleaning, and analysis) is still ongoing. Preliminary results based on data from Kenya indicate that even though agriculture is the main source of income and other aspects of improved livelihoods, households tended to pay less attention to farm input-related expenses (mineral fertilizers, organic fertilizers, seeds, etc.) when allocating their little financial resources. Preference is often given to items such as paraffin, food, health and medication and social contributions. Our results also show a high wealth inequality among farm households in western Kenya. This was in terms of both household wealth (with a *Gini-coefficient* of 0.52) and per capita wealth (with a *Gini-coefficient* of 0.55). The high level of inequality calls for more attention on proper targeting of pro-poor development activities to ensure that the poorest of the poor are adequately catered for.

Baseline study on soybeans (production, processing, utilization and marketing) in the farming systems of East Africa (Kenya, Uganda, and Tanzania)

J. Chianu[1], B. Vanlauwe[1], P. Kalunda[2], H. de Groote[3], N. Sanginga[1], A. Adesina[4], F. Myaka[5], Z. Mkangwa[5], and J. Opondo[6]

[1]TSBF-CIAT, Kenya; [2]NARO, Uganda; [3]CIMMYT, Kenya; [4]Rockefeller Foundation, Kenya ; [5]Ilonga Research Institute, Tanzania; [6]Dominion Farms, Siaya District, Kenya

Soybean was introduced in the farming systems of Kenya, Uganda, and Tanzania many decades ago. However, the crop has remained a minor crop despite its great potentials for improving household food and nutrition security (through quality food supply), household cash income (through the sales of soybean and soybean products), household health (through the provision of high quality protein-rich food), and soil fertility improvement (through its atmospheric nitrogen-fixing ability). Literature indicates that low yield, lack of knowledge on its utilization, and lack of market are among the key factors that have contributed to lack of adoption of soybeans in the farming systems of East Africa. A recent effort based on improved dual-purpose promiscuous soybeans varieties sourced from IITA, Ibadan, Nigeria has been commenced by TSBF-CIAT.

This study aims at documenting the baseline data (on production, processing, utilization, and marketing) in order to have sufficient information to assess the impact of the improved dual-purpose promiscuous soybeans varieties on the soybean sub-sector in East Africa in future.

This study is being carried out in selected districts in the three countries. Data for the attainment of the objective of this study are being collected from primary sources (household-level and community-level surveys using questionnaires), secondary sources (reports, published articles, books, etc.) and key informant interviews. Data processing is being executed using many computer applications including Microsoft Excel, SPSS, and SAS.

Data collection for both the Kenya and the Uganda arms of the study has been completed. The data have also been entered into the computer and are currently being processed (including validation and cleaning, and analysis). The implementation of the baseline community-level and household-level socioeconomic data collection in Tanzania has commenced with the listing of the male and female farmers who grow or do not grow soybean in two villages (*Kidegembye* and *Image*) selected from *Njombe* district. The distribution of household with respect to soybean growing status and gender of household head is as in Table 28 below.

Table 28. Summary of households (number) listed in two villages in *Njombe* district of Tanzania.

Village	Soybean growing status	Gender of household head		Total
		Male-headed	Female-headed	
Kidegembye	Soybean growing	30	26	56
	Non-soybean growing	322	218	540
Image	Soybean growing	42	0	42
	Non-soybean growing	467	200	667
Total across soybean growing status		861	444	1305

Source: Summarized from household listing data, 2006/2007

Using these frames, the baseline community-and household-level surveys are planned for the second half of 2007.

Output target 2009

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

Published work

Okalebo[1], J.R., Othieno[1], C.O., Woomer[2], P.K., Karanja[3], N.K., Semoka[4], J.R.M., Bekunda[5], M.A., Mugendi[6], D.N., Muasya[7], R.M., Bationo[8], A. and Mukhwana[2], E.J. (2006) Available technologies to replenish soil fertility in East Africa. Nutrient Cycling in Agroecosystems 76:153–170
[1]Moi University Eldoret, Kenya; [2]SACRED Africa, Kenya; [3]University of Nairobi, Kenya; [4]Sokoine University, Tanzania; [5]Makerere University, Uganda; [6] Kenyatta University, Kenya;; [8]TSBF – CIAT, Kenya
Abstract: Low inherent soil fertility in the highly weathered and leached soils largely accounts for low and unsustained crop yields in most African countries. But in particular, the major nutrients, nitrogen (N) and phosphorus (P) are commonly deficient in these soils. This scenario of nutrient depletion is reflected in food deficits and hence the food aid received continuously, specifically in sub-Saharan Africa. Undoubtedly, substantial efforts have been made in the continent to replenish the fertility of degraded soils in attempts to raise crop yields, towards self-sufficiency and export. Such efforts consist of applications of both organic and inorganic resources to improve the nutrient status of soils and enhanced nutrient uptake by crops, provided that soil moisture is adequate. Overall, positive crop responses to these materials have been obtained. Thus in the East African region, maize (staple) yields have been raised in one growing season from below 0.5 t ha^{-1} without nutrient inputs, to 3–5 t ha^{-1} from various nutrient amendments at the small hold farm level. However, in spite of the positive crop responses to nutrient inputs, farmers are generally slow to adopt the soil fertility management technologies. In this paper we review the impact of some technologies, focusing the use of nutrient resources of different characteristics (qualities) in relation to improved crop yields, with an overall goal to enhance technology adoption. Thus, inorganic resources or fertilizers often give immediate crop responses, but their use or adoption is rather restricted to large-scale farmers who can afford to buy these materials. Organic resources, which include crop residues, water hyacinth and agro forestry shrubs and trees, are widely distributed, but they are generally of low quality, reflecting the need to apply large quantities to meet crop nutrient demands. Moreover, most organics will add N mainly to soils. On the other hand, phosphate rocks of varying reactivity are found widely in Africa and are refined elsewhere to supply soluble P sources.

The recently developed soil fertility management options in East Africa have targeted the efficient use of N and P by crops and the integrated nutrient management approach. Some people have also felt that the repackaging of inputs in small, affordable quantities, such as the PREP-PAC described in this paper, may be an avenue to attract small hold farmers to use nutrient inputs. Nonetheless, crop responses to nutrient inputs vary widely within and across agroecozones (AEZs), suggesting specificity in recommendations. We highlight this observation in a case study whereby eight soil fertility management options, developed independently, are being tested side-by-side at on-farm level. Farmers will be empowered to identify technologies from their own choices that are agronomically effective and economically friendly. This approach of technology testing and subsequent adoption is recommended for technology development in future.

Mafongoya[1], P.L., Bationo[2], A., Kihara[2], J. and Waswa[2], B.S. (2006) Appropriate technologies to replenish soil fertility in southern Africa. Nutrient Cycling in Agroecosystems 76:137–151
[1]ICRAF,Zambia, [2]TSBF – CIAT
Abstract: In southern Africa, soil nutrient reserves are being depleted because of continued nutrient mining without adequate replenishment. The consequent downward spiral of soil fertility has led to a

corresponding decline in crop yields, food insecurity, food aid and environmental degradation. The central issue for improving agricultural productivity in southern Africa is how to build up and maintain soil fertility despite the low incomes of smallholder farmers and the increasing land and labour constraints they face. Under this review five main options namely: inorganic fertilizers, grain legumes, animal manures, integrated nutrient management and agroforestry options appropriate to smallholder farmers are presented. Issues addressed in the use of inorganic fertilizers are reduction in fertilizer costs, timely availability and use efficiency. Legumes can be used to diversify farm system productivity but this requires P and lime application to support better legume growth and biological nitrogen fixation (BNF) as well as development of markets for various legume products. Manure availability and quality are central issues in increasing smallholder farm productivity and increasing its efficiency through proper handling and application methods. Integrated nutrient management of soil fertility by combined application of both inputs will increase use efficiency of inputs and reduce costs and increase profitability; but the challenge is often how to raise adequate amounts of either inorganic or organic inputs. Issues such as quality of inputs, nutrient balancing, labour to collect and transport organic inputs and their management need to be optimized. These are the challenges of adoption as are the scaling up of these options to millions of small-scale farmers.

Fatondji[1], D., Martius[2], C., Bielders[3], C.L., Vlek[2], P.L.G., Bationo[4], A. and Gerard[1], B. (2006) Effect of planting technique and amendment type on pearl millet yield, nutrient uptake, and water use on degraded land in Niger. Nutrient Cycling in Agroecosystems 76:203–217

[1]ICRISAT-Niger; [2]ZEF, UNI-Bonn, Germany; [3]Universite´ catholique de Louvain (ULC), Belgium; [4]TSBF-CIAT,Kenya

Abstract: Due to increased population pressure and limited availability of fertile land, farmers on desert fringes increasingly rely on marginal land for agricultural production, which they have learned to rehabilitate with different technologies for soils and water conservation. One such method is the indigenous zai technique used in the Sahel. It combines water harvesting and targeted application of organic amendments by the use of small pits dug into the hardened soil. To study the resource use efficiency of this technique, experiments were conducted 1999–2000, on-station at ICRISAT in Niger, and on-farm at two locations on degraded lands. On-station, the effect of application rate of millet straw and cattle manure on millet dry matter production was studied. On-farm, the effects of organic amendment type (millet straw and cattle manure, at the rate of 300 g per plant) and water harvesting (with and without water harvesting) on millet grain yield, dry matter production, and water use were studied. First, the comparison of zai vs. flat planting, both unamended, resulted in a 3- to 4-fold (in one case, even 19-Fold) increase in grain yield on-farm in both years, which points to the yield effects of improved water harvesting in the Zai alone. Zai improved the water use efficiency by a factor of about 2.

The yields increased further with the application of organic amendments. Manure resulted in 2–68 times better grain yields than no amendment and 2–7 times better grain yields than millet straw (higher on the more degraded soils). Millet dry matter produced per unit of manure N or K was higher than that of millet Straw, a tendency that was similar for all rates of application. Zai improved nutrient uptake in the range of 43–64% for N, 50–87% for P and 58–66% for K. Zai increased grain yield produced per unit N (8 vs. 5 kg kg^{-1}) and K (10 vs. 6 kg kg^{-1}) compared to flat; so is the effect of cattle manure compared to millet straw (9 vs. 4 kg kg^{-1}, and 14 vs. 3 kg kg^{-1}), respectively, Therefore zai shows a good potential for increasing agronomic efficiency and nutrient use efficiency. Increasing the rate of cattle manure application from 1 to 3 t ha^{-1} increased the yield by 115% TDM, but increasing the manure application rate further from 3 to 5 t ha^{-1} only gave an additional 12% yield increase, which shows that optimum application rates are around 3 t ha^{-1}.

Kimetu[1,7], J.M., Mugendi[2], D.N., Bationo[1], A., Palm[3], C.A., Mutuo[4], P.K., Kihara[1], J., Nandwa[5], S. and Giller[6], K. (2006) Partial balance of nitrogen in a maize cropping system in humic nitisol of Central Kenya. Nutrient Cycling in Agroecosystems 76: 261-270

[1]TSBF-CIAT), Kenya; [2]Kenyatta University, Kenya; [3]The Earth Institute at Columbia University, USA; [4]World Agroforestry Centre (ICRAF),Kenya; [5]National Agricultural Research Laboratories (NARL), Kenya; [6]Wageningen University, The Netherlands; [7]Cornell University, USA

Abstract: The application of nitrogen in a soil under agricultural production is subject to several pathways including de-nitrification, leaching and recovery by an annual crop. This is as well greatly influenced by the management practices, nitrogen source and soil conditions. The main objective of this study was to investigate the loss of nitrogen (N) through nitrous oxide (N_2O) emissions and mineral N leaching and uptake by annual crop as influenced by the N source. The study was carried out at Kabete in Central Kenya. Measurements were taken during the second season after two seasons of repeated application of N as urea and *Tithonia diversifolia* (tithonia) leaves. Results obtained indicated that nitrous oxide (N_2O) emissions at 4 weeks after planting were as high as 12.3 lg N m^{-2} h^{-1} for tithonia treatment and 2.9 lg N m^{-2} h^{-1} for urea treatment. Tithonia green biomass treatment was found to emit N_2O at relatively higher rate compared to urea treatment. This was only evident during the fourth week after treatment application. Soil mineral N content at the end of the season increased down the profile. This was evident in the three treatments (urea, tithonia and control) investigated in the study. Urea treatment exhibited significantly higher mineral N content down the soil profile (9% of the applied N) compared to tithonia (0.6% of the applied N). This was attributed to the washing down of the nitrate-N from the topsoil accumulating in the lower layers of the soil profile. However, there was no significant difference in N content down the soil profile between tithonia treatment and the control. It could be concluded that there was no nitrate leaching in the tithonia treatment. N recovery by the maize crop was higher in the urea treatment (76% of the applied N) as compared to tithonia treatment (55.5% of the applied N). This was also true for the residual mineral N in the soil at the end of the season which was about 7.8% of the applied N in the urea treatment and 5.2% in the tithonia treatment. From this study, it was therefore evident that although there is relatively lower N recovery by maize supplied with tithonia green biomass compared to maize supplied with urea, more nitrogen is being lost (through leaching) from the soil–plant system in the urea applied plots than in tithonia applied plots. However, a greater percentage (37.8%) of the tithonia-applied N could not be accounted for and might have been entrapped in the soil organic matter unlike urea-applied N whose greater percentage (92%) could be accounted for.

Mtambanengwe[1], F., Mapfumo[1], P. and Vanlauwe[2], B. (2006) Comparative short-term effects of different quality organic resources on maize productivity under two different environments in Zimbabwe. Nutrient Cycling in Agroecosystems 76:271-284

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Abstract: Major challenges for combined use of organic and mineral nutrient sources in smallholder agriculture include variable type and quality of the resources, their limited availability, timing of their relative application and the proportions at which the two should be combined. Short-term nutrient supply capacity of five different quality organic resources ranging from high to low quality, namely *Crotalaria juncea*, *Calliandra calothyrsus*, cattle manure, maize stover and *Pinus patula* sawdust were tested in the field using maize as a test crop. The study was conducted on two contrasting soil types at Makoholi and Domboshawa, which fall under different agro-ecological regions of Zimbabwe. Makoholi is a semi-arid area (<650 mm yr^{-1}) with predominantly coarse sandy soils containing approximately 90 g kg^{-1} clay while Domboshawa (>750 mm yr^{-1}) soils are sandy-clay loams with 220 g kg^{-1} clay. Each organic resource treatment was applied at low (2.5 t C ha^{-1}) and high (7.5 t C ha^{-1}) biomass rates at each site.

Each plot was sub-divided into two with one half receiving 120 kg N ha^{-1} against zero in the other. At Makoholi, there was a nine-fold increase in maize grain yield under high application rates of C.juncea over the unfertilized control, which yielded only 0.4 t ha^{-1}. Combinations of mineral N fertilizer with the leguminous resources and manure resulted in between 24% and 104% increase in grain yield against sole

fertilizer, implying an increased nutrient recovery by maize under organic -mineral combinations. Maize biomass measured at 2 weeks after crop emergence already showed treatment differences, with biomass yields increasing linearly with soil mineral N availability (R^2= 0.75). This 2-week maize biomass in turn gave a positive linear relationship (R^2= 0.82) with grain yield suggesting that early season soil mineral N availability largely determined final yield. For low quality resources of maize stover and sawdust, application of mineral N fertilizer resulted in at least a seven-fold grain yield increase compared with sole application of the organic resources. Such nutrient combinations resulted in grain harvest indices of between 44% and 48%, up from a mean of 35% for sole application, suggesting the potential of increasing maize productivity from combinations of low quality resources with mineral fertilizer under depleted sandy soils. At Domboshawa, grain yields averaged 7 t ha^{-1} and did not show any significant treatment differences. This was attributed to relatively high levels of fertility under the sandy-clay loams during this first year of the trial implementation. Differences in N supply by different resources were only revealed in grain and stover uptake. Grain N concentration from the high quality leguminous resources averaged 2% against 1.5% from sawdust treatments. We conclude that early season soil mineral N availability is the primary regulatory factor for maize productivity obtainable under poor sandy soils. Maize biomass at 2 weeks is a potential tool for early season assessment of potential yields under constrained environments. However, the likely impact on system productivity following repeated application of high N-containing organic materials on different soil types remains poorly understood.

Ouattara[1], B., Ouattara[1], K., Serpantie[2], G., Mando, A., Se´dogo[1], M.P. and Bationo, A. (2006) Intensity cultivation induced effects on soil organic carbon dynamic in the western cotton area of Burkina Faso. Nutrient Cycling Agroecosystem 76: 331–339

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Abstract: The soil organic carbon (SOC) dynamic is a key element of soil fertility in savannah ecosystems that form the key agricultural lands in sub-Saharan Africa. In the western part of Burkina Faso, the land use is mostly linked to cotton-based cropping systems. Use of mechanization, pesticides, and herbicides has induced modifications of the traditional shifting cultivation and increased the need for sustainable soil fertility management. The SOC dynamic was assessed based on a large typology of land cultivation intensity at Bondoukui. Thus, 102 farm plots were sampled at a soil depth of 0–15 cm, considering field–fallow successions, the cultivation phase duration, tillage intensity, and soil texture. Physical fractionation of SOC was carried out by separating the following particle size classes: 2,000–200, 200–50, 50–20, and 0–20 lm. The results exhibited an increase in SOC stock, and a lower depletion rate with increase in clay content. After a long-term fallow period, the land cultivation led to an annual loss of 31.5 g m^{-2} (2%) of its organic carbon during the first 20 years. The different fractions of SOC content were affected by this depletion depending on cultivation intensity. The coarse SOC fraction (2,000–200 lm) was the most depleted. The ploughing-in of organic matter (manure, crop residues) and the low frequency of the tillage system produced low soil carbon loss compared with annual ploughing. Human-induced disturbances (wildfire, overgrazing, fuel wood collection, decreasing fallow duration, increasing crop duration) in savannah land did not permit the SOC levels to reach those of the shifting cultivation system.

Vanlauwe[1], B., Tittonell[2], P. and Mukalama[1], J. (2006) Within-farm soil fertility gradients affect response of maize to fertilizer application in western Kenya. Nutrient Cycling in Agroecosystems 76: 171-182

TSBF-CIAT, Nairobi, Kenya

Abstract: Different fields within a farm have been observed to have different soil fertility status and this may affect the response of a maize crop to applied N, P, and K fertilizer. A limiting nutrient trial was carried out at six farms each, in three districts of Western Kenya. In each of the farms, the following treatments were laid out in three fields with different soil fertility status at different distances from the homestead (close, mid-distance, remote fields): no inputs, application of NPK, NP, NK, or PK fertilizer (urea, triple super phosphate, KCl) to maize. Total soil N decreased at all sites with distance to the

homestead (from 1.30 to 1.06 g kg^{-1}), as did Olsen-P (from 10.5 to 2.3 mg kg^{-1}). Grain yields in the no-input control plots reflected this decrease in soil fertility status with distance to the homestead (from 2.59 to 1.59 Mg ha^{-1}). In the NPK treatments, however, this difference between field types disappeared (from 3.43 to 3.98 Mg ha^{-1}), indicating that N and P are the major limiting nutrients in the target areas. Response to applied N was related to the soil total N content in Aludeka and Shinyalu, but not in Emuhaya, probably related to the high use of partially decomposed organic inputs with limited N availability. Consequently, response to applied N decreased with distance to the homestead in Aludeka (from 0.95 kg kg^{-1} relative yield to 0.55 kg kg^{-1}) and Shinyalu (from 0.76 kg kg^{-1} to 0.47 kg kg^{-1}), but not in Emuhaia (from 0.75 kg kg^{-1} to 0.68 kg kg^{-1}). Response to applied P was related to the soil Olsen-P content at all sites. While for farms with a relatively high Olsen-P gradient, response to applied P decreased with distance to the homestead (from 0.99 kg kg^{-1} to 0.68 kg kg^{-1}), large variability in Olsen-P gradients across field types among farms within a specific site often masked clear differences in response to P between field types for a specific site. Clear scope for field-specific fertilizer recommendations exists, provided these are based on local soil knowledge and diagnosis. Scenario analysis, using farm-scale modelling tools, could assist in determining optimum allocation strategies of scarcely available fertilizer for maximum fertilizer use efficiency.

Bationo,[1] A., Vanlauwe, B., Kihara, and Kimetu, J. (2007) Soil organic carbon dynamics, functions and management in West African agro-ecosystems. Agriculture Systems 94: 13-25
TSBF-CIAT, Nairobi, Kenya
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 a 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 SOC 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.

Completed work

Innovations for increasing productivity through improved nutrient use in Africa

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Poor soil fertility is regarded as the underlying factor limiting productivity in African agriculture. Substantial knowledge has been accumulated on different approaches to manage soil fertility in smallholder farms in Africa. Nevertheless the lack of adoption of various technologies, or the absence of widespread testing and experimentation by farmers, are often disappointing. We argue that this is related to the lack of integration of available knowledge and the lack of holistic and participatory approaches that foster technical and institutional change. Systems approaches, employing relatively simple summary type models across disciplines, can help disentangle the complexity of farmer decision making at farm scale. Such decision-making is often a compromise between the potential for short-term maximization of crop and livestock production and investment for sustainable production in the long term. An example is the NUANCES (Nutrient Use in Animal and Cropping systems – Efficiency and Scales) framework that assists with the analyses of different soil improving technologies in the context of farmers' strategies. It allows for spatial and temporal variability of resource use and access to land, labour, technologies and markets. Spatial patterns of soil fertility are often very pronounced in Africa, with farmers preferentially allocating manure, mineral fertilizers and labour to fields close to the homestead, resulting in strong soil fertility gradients at farm and village level.

We show that clear scope for field-specific fertilizer management recommendations exists, provided they are based on local soil knowledge and diagnosis. Tools such as NUANCES are useful as they allow for ex-ante analyses and allow targeting technologies to specific types of farmers, and for identification of more appropriate technologies. They can for example help in determining optimum allocation strategies of mineral fertilizers across farms to enhance their efficiency. To promote innovations for increasing productivity through improved nutrient use in Africa will require holistic and dynamic approaches that foster both technical and institutional change, based on solid understanding of the farmer context. This involves the participatory development of soil management technologies with coordinated efforts to experiment and extend alternative institutional arrangements that link farmers with input-dealers, rural bankers and traders and strengthens the innovative capacities of the various stakeholders involved. A major challenge is to find pathways for action that recognize the heterogeneity of institutions and the diversity and conflicting agendas of the actors involved. Systemic inquiry by multi-disciplinary 'teams', involving facilitators from different institutions, is needed. Such teams need to place more emphasis on farmer experimentation and adaptation according to the prevailing agro-ecological and socio-economic conditions rather than on technology prescriptions.

Assessment of cowpea and groundnut contributions to soil fertility and succeeding sorghum yields in the Guinean savannah zone of Burkina Faso (West Africa)

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Atmospheric biological nitrogen fixation (BNF) by cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogea*) was evaluated using a two years (2000-2001) experiment with deferent fertilizer treatments. The ^{15}N isotopic dilution method with a non-fixing cowpea as test reference crop was used. The effects of the two legumes on soil N availability and succeeding sorghum (*Sorghum bicolor*) yields were measured. Groundnut fixed 8 to 23 kg N ha^{-1} and the percentage of N derived from the atmosphere varied from 27 to 34%. Cowpea fixed 50 to 115 kg N ha^{-1} and the percentage of N derived from the atmosphere varied from 52 to 56%. Compared to mineral NPK fertilizer alone, legumes fixed more N from the atmosphere when dolomite or manure was associated with mineral fertilizers. Compared to soluble phosphate, phosphate rock increased BNF by cowpea. Significant correlation (p{0.05, R^2=0.94) was observed between total N yields of legumes and total N derived from atmosphere. Compared to mono cropping of sorghum, the soils of cowpea-sorghum and groundnut-sorghum rotations increased soil mineral N from 15 and 22 kg N ha^{-1}, respectively. Cowpea-sorghum and groundnut-sorghum rotations doubled N uptake and increased succeeding sorghum yields from 290 and 310%, respectively. Results suggested that, despite their ability to fix atmospheric nitrogen, N containing fertilizers (NPK) are recommended for the two legumes. The applications of NPK associated with dolomite or cattle manure or NK fertilizer associated with phosphate rock were the better recommendations which improved BNF, legumes and succeeding sorghum yields.

Improving soil fertility through the use of organic and inorganic plant nutrient and crop rotation in Niger

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Food production can be increased through the integration of organic and inorganic nutrient sources coupled with proper land management. Niger is one of the poorest countries in the Sahelian zone of West Africa where soil fertility and rainfall are the most limiting factors for crop production. The majority of the people in this region depend on subsistence agriculture for their livelihood. The population pressure has decreased the availability of arable land and the use of extended fallow periods to restore soil fertility is not possible.

Research results have shown that yields can be increased up to five times with the improvement of soil fertility using a combination of soil tillage, organic and inorganic fertilizers than under traditional practice. Crop yields have also been shown to increase substantially using rotation of cereals with legume or intercropping. Yields of pearl millet can be doubled following cowpea as compared to continuous pearl millet cultivation. These combinations can improve soil properties such as organic carbon content, Cation Exchange Capacity (CEC) and pH.

There is however a constraint to the applicability of combining inorganic and organic fertilizers due to the high costs of inorganic fertilizers and the low availability of organic fertilizers at the farm level. But it can be addressed by incorporating grain legume production such as cowpea into the cropping system. The grain, which has high market value, can be sold for buying external inputs such as fertilizer and fodder used for animal feeding. The use of external inputs will result in an increasing biomass at farm level, which increases the crop residue for mulching to mitigate land degradation and increase productivity.

Mineral fertilizers, organic amendments and crop rotation managements for soil fertility maintenance in the Guinean zone of Burkina Faso (West Africa)

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

Performance evaluation of various agroforestry species as short duration improved fallows for enhancement of soil fertility and sorghum crop yields in Mali

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The general soil fertility and crop yield decline constraints have guided the Malian Agricultural Research Institute (Institut d'Economie Rurale, IER), the Sahel Program of the World Agroforestry Centre (ICRAF) and the International Crops Research Institute for the Semi Arid Tropics (ICRISAT) to join efforts and undertake research activities aimed at mitigating the constraints in Mali. Thus, from the year 2000 14 different trees and shrubs are being tested in improved fallow systems to find which ones perform best to replenish soils and improve crop yields.

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

Increasing land productivity and optimising benefits in legume-cereal rotations through nitrogen and phosphorus management in western Kenya

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Combined application of organic resources and mineral inputs forms the technical backbone of the Integrated Soil Fertility Management approach. In-situ production of organic matter is an attractive alternative to technologies harvesting the organic resources from other sites within or outside the farm. Opting for legumes during the organic resource production phase has the potential to enrich the soil with nitrogen (N) through biological N_2 fixation. An experiment was set up at Nyabeda in Western Kenya aimed at quantifying the contribution of herbaceous and grain legumes to nitrogen supply and the impact of targeting phosphorus (P) to certain phases of the rotation on overall maize grain yield. In this split-split plot experiment, *Mucuna pruriens* was used as the herbaceous legume while soybean was used as the grain legume. Results obtained in the two seasons of the study indicated that the use of either mucuna or soybean as previous crop significantly (P=0.05) increased maize grain yield with or without the addition of nitrogen fertilizer, although mucuna out performed soybean. More than 5 t ha^{-1} of maize grain yield was realized with the addition of phosphorus fertilizer at both season one and season two compared to about 3 t ha^{-1} of maize grain yields obtained when no P was added.

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

Tied-ridging and integrated nutrient management options for sustainable crop production in semi-arid eastern Kenya.

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A field experiment was conducted for two seasons at Emali, Makueni District in Eastern Kenya to compare the effect of tied ridging and integrated nutrient management practices on the yield of rainfed maize (*Zea mays* L.) and cowpeas (*Vigna unguiculata* L.). The main treatments were flat bed (FB, traditional farmers' practice) and tied ridging (TR) as main plots. The manure and fertilizers were farmyard manure (FYM, goat manure at 0 and 5 t ha^{-1}) in a factorial combination with nitrogen (N fertilizer at 0, 40, 80 and 120 kg N ha^{-1}) and P fertilizer at 0 and 40 kg P ha^{-1} as the subplots in a split-plot treatment arrangement of a randomized complete block design (RCBD). Results from maize yield data in the continuous maize cropping systems indicate that maize stover was significantly (PÒ0.05) increased by the application of 5 t ha^{-1} of manure in both seasons. Tied ridges, manure and fertilizer did not affect grain yields in the first season. However, mean grain yields obtained in plots with tied-ridges and manure were higher by 11% and 14% compared to plots without tied ridges and manure respectively. There was a significant interaction between manure and nitrogen which gave higher stover yields in the 2003 long rains season. Under the cowpeas-maize intercropping system, tied ridges and manure application did not have a significant effect on maize yields in both seasons. Application of nitrogen significantly (PÒ0.05) increased maize stover by 29% and TDM yields by 50% in first and second season respectively when compared with treatments without nitrogen. Nitrogen application also increased cowpea stem and TDM yields by 57% and 45% respectively in the second season. Cowpea yields were not affected by tied-ridges in both seasons. There was significant effects of manure, nitrogen, manure*nitrogen and tied ridging*nitrogen interactions on cowpea stem and TDM in 2003 short rains season. In general, the combination of tie-ridges with manure or nitrogen gave higher maize and cowpea yields than when these factors are applied alone. These preliminary results indicate that tied ridging in combination with integrated nutrient management has the potential to improve crop production in semi-arid eastern Kenya

Effects of organic and mineral sources of nutrients on maize yields in three districts of central Kenya

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Trials were set up in three districts of central Kenya to evaluate organic and mineral sources of nutrients and their effects on maize yields. The experiments were set up during the long rains 2004 with fifteen different soil fertility management treatments. The treatments included cattle manure, green manures, maize stover, *Tithonia*, and mineral fertilizer. The test crop was maize (*Zea mays*), intercropped with beans (*Phaseolus vulgaris*). The experimental design was a Randomized Complete Block with three replicates. At final harvest at maturity, grain yield data were recorded.

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

Output target 2009

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

Progress towards this output target will be reported next year.

Progress towards achieving output level outcome

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

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

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

The development and evaluation of technologies aiming at improving the productivity of banana and cassava-based systems in Africa and cereal-legume-livestock systems in Latin America have just reached the initial design phase with promising initial results related to nutrient management of bananas and inoculation of tissue culture bananas with arbuscular-mycorrhizal fungi. The evaluation work on direct and indirect management options of belowground biodiversity and the Quesungual agroforestry systems has resulted in significant research accomplishments.

Progress towards achieving output level impact

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

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