4.5 OUTPUT 5. Sustainable land management for social profitability developed, with special emphasis on reversing land degradation

Rationale

The economy of low income countries need to grow steadily at a rate of 3.6% annually in order to achieve the Millennium Development goal of reducing by half the global population living with less than 1US/day by 2015. Agriculture is an essential component for the environmentally and socially sustainable development of developing countries. Balancing higher agricultural productivity and access to markets with the maintenance of the resource base and the quality of the environment is a major challenge that requires integration of knowledge and policies across scales ranging from farm to landscape level.

Strategic and component research to date has been conducted largely at the plot or field scale, where interactions among various agricultural enterprises are seldom considered. Although TSBF-CIAT's strength remains at the plot level, the diversity of forces impinging on the plot naturally draws attention towards a hierarchical systems-based approach. The next generation of work will be at higher scales, particularly the farm and landscape scales. The rationale for working at the farm scale is the need to improve nutrient use efficiency through better allocation of the limited organic and inorganic resources among different enterprises, taking into consideration the inherent soil variability within the farming system. Inadequacies in supplies of both organic and inorganic nutrients have created strong fertility gradients even within the smallest farms. Smallholder farmers typically remove harvest products and crop residues from their food producing 'outfields' and devote their scarce soil inputs to their smaller market 'infields', resulting in large differences in soil productivity over time between these two field types. Understanding how to manage the limited nutrient supplies across such fertility gradients is a key component in raising productivity in fields of staple crops.

Agriculture needs economic soil management practices that provide sufficient food and yet maintain environmental stability, ecological integrity, and the quality of essential resources. Strategies for sustainable land management include conserving essential soil components, minimizing erosion, balancing production with environmental needs, and making better use of renewable resources. In this regard, soil health is a major indicator of sustainable land management. Criteria for indicators of soil health are useful in defining ecosystem processes and sensitivity to managements and climatic variations and in integrating physical, chemical and biological soil properties. Land users and decision makers need to use those criteria for implementing sustainable land management practices.

Interest in the quality and health of soil has grown with the recognition that soil is vital not only to production of food and fiber, but also for the smooth functioning of the ecosystem and overall environmental stability. Soils play a central role for the provision of ecosystem services such as regulation of water quality and quantity, biodiversity, carbon storage and net fluxes of greenhouse gases to the atmosphere. Appropriate soil management could result in enhanced provision of such services. However, reliable and cost effective assessment of such services at farm and landscape level and the development of mechanisms to compensate farmer communities that manage the soils, remain to be major challenges. TSBF-CIAT intends to contribute to fill this gap in knowledge through partnerships with other CIAT projects and with regional Consortia (AFNET, MIS, CONDESAN, the Amazon Initiative).

Projections indicate that eastern and southern Africa, and Central America will be critically short of water in the coming decades. Extending TSBF-CIAT's research agenda to address water issues to these regions is required. The new proposals approved by the Water and Food Challenge Program for the Volta basin in West Africa and on the Quesungual slash/mulch agroforestry system in Central America offer the opportunity to address constraints related to water and its interaction with soil fertility, soil erosion and other ecosystem services.

Milestones

- By 2007, identification, characterization, and monitoring of degraded lands available for at least 2 regions.
- By 2008 methods for socioeconomic evaluation/valuation of ecosystem services for trade-off and policy analysis used, at least in 2 humid and 2 sub-humid Agro-ecological zones.
- By 2010, 30% of partner farmers in pilot sites used SLM options that increase productivity and arrest resource degradation

Highlights

- Main factors influencing maize production in the Quesungual agroforestry system included altitude of farms above sea level, phosphorus fertilizer input and the density of the tree component.
- Showed that the high potential of the NIRS (Near Infrared Reflectance Spectrometry) for evaluating soil quality in large areas, rapidly, reliably and economically, thereby facilitating decision-making with respect to soil management and conservation
- Found that the savannas from Colombia and Venezuela have an estimated total carbon stock of 3.1 Pg C in the top 30 cm of the soil. Projected intensification of agriculture, livestock and forestry in the region in the next two decades could result in a net increase of 160 Tg of C in the soil stocks.
- Diverse land use systems in the Fuquene watershed, result in drastic differences in the degree of limitation to root growth. Degraded land show extremely high values that virtually impede any plant establishment and growth.

5.1 Identify & characterize biophysical, social & policy niches where different technologies to address land degradation in the landscape will fit

On-going Work of AfNet

I. <u>Long term trials</u>

The objective of these network activities is to develop and implement management options that both mitigate soil degradation, deforestation and biological resource losses and enhance local economies while protecting the natural resource base.

In 2003, trials were established at four representative benchmark sites in some important agro-ecological zones of Niger (West Africa) (Table 45). On-station and on-farm researcher managed and farmer-managed trials were carried out. Through the Rockefeller grant in West Africa, a vital link was established between TSBF and collaborating institutions in West Africa especially ICRISAT.

1. Long-term soil fertility management trials

a) Long-term management of phosphorus, nitrogen, crop residue, soil tillage and crop rotation in the Sahel

Since 1986 a long-term soil fertility management was established by ICRISAT Sahelian Center to study the sustainability of pearl millet based cropping systems in relation to management of N, P, and crop residue, rotation of cereal with cowpea and soil tillage. The data in Table 46 gives the main treatments in this trial. In this split-split-plot design the split-split plot consisted of crop residue application or no crop residue application consisting of leaving half of the total crop residue produced in the plot and the sub-sub plot was with or without nitrogen application.

Table 45. Network collaborative trials in Niger (West Africa), 2003.

Type of Trials	Site
Long-term operational scale research	Sadore
Long-term cropping system	Sadore
Long-term crop residue management	Sadore
On-farm evaluation of cropping systems technologies	Sadore,Karabedji Gaya
On-farm evaluation of soil fertility restoration technologies	Karabedji, Gaya
Comparative effect of mineral fertilizers on degraded and non degraded soils	Karabedji
Fertilizer equivalency and optimum combination of low quality organic and inorganic plant nutrients	1. Banizoumbou, 2.Karabedji, 3. Gaya
Monitoring nutrient budget	Banizoumbou
Biological nitrogen fixation	Banizoumbou, Gaya
Corral experiment (demonstration)	Sadore

Table 46. Main treatments used in the Integrated Soil Fertility Management trials at Sadore

1= Traditional practices
2= Animal traction (AT) +no rotation +Intercropping + P
3= Animal traction (AT) + rotation +Intercropping + P
4= Hand Cultivation (HC) +no rotation +Intercropping + P
5= Hand Cultivation (HC) + rotation +Intercropping + P
6= Animal traction (AT) +no rotation +Pure millet + P
7= Animal traction (AT) + rotation + Pure millet + P
8= Hand Cultivation (HC) +no rotation + Pure millet + P
9= Hand Cultivation (HC) + rotation + Pure millet + P

The traditional farmers' practice yielded 73 kg/ha of pearl millet grain whereas with application of 13 kg P/ha, 30 kg N/ha and crop residue in pearl millet following cowpea yielded 1471 kg/ha of pearl millet grain (Table 47). These results clearly indicate the high potential to increase the staple pearl millet yields in the very poor Sahelian soils.

Table 47. Effect of fertilizers, soil tillage, crop residue, cropping system on pearl millet grain yield; Sadore 2003 cropping season.

Treatments	Pure millet grain yield (kg/ha)							
	- Rotation				+ Rotation			
	- Crop residue		+ Crop residue		- Crop residue		+ Crop residue	
	-N	+N	-N	+N	-N	+N	-N	+N
Traditional	73	86	83	119				
Phosphorus + HC	299	818	479	909	341	699	851	1212
Phosphorus + AT	526	836	670	1028	870	1128	1048	1471

HC: hand cultivation, planting on flat; AT: Animal traction, planting on ridges

b) Long-term management of manure, crop residues and fertilizers in different cropping systems

Since 1993 a factorial experiment was initiated at the research station of ICRISAT Sahelian Center at Sadore, Niger. The first factor was three levels of fertilizers (0, 4.4 kg P + 15 kg N/ha, 13kg P + 45 kg N/ha), the second factor was crop residue applied at (300, 900 and 2700 kg/ha) and the third factor was manure applied at (300, 900 and 2700 kg/ha). The cropping systems are continuous pearl millet, pearl millet in rotation with cowpea and pearl millet in association with cowpea. The analysis of variance data indicate that fertilizer; crop residue and manure application resulted in a highly significant effect of both pearl millet grain and total dry matter yields. Fertilizer alone account for 47% in the total variation of the dry matter whereas manure account for 17%. Although some interactions are significant they account for les than 2% in the total variation.

For pearl millet grain, the application fertilizer, manure, crop residue and cropping systems alone account for 66% of the total variation. The data in Figure 35 illustrate the response of pearl millet grain to crop rotation and different input of organic and inorganic fertilizers. The farmer's practices yield 335 kg/ha; the application of 13 kg P and 45 kg N/ha yielded 834 kg/ha but when these mineral fertilizers are combined with 2.7 t/ha of manure or crop residue in rotation with cowpea, yield of 1584 kg/ha can be achieved. The N and P fertilizer value of manure and crop residue is 45 and 13 respectively and the N and P equivalency of manure is 87% and 65% for crop residue (Table 48). The high values of fertilizers equivalency of manure and crop residue suggest that the organic amendment have beneficial roles other than the addition of plant nutrient such as addition of micronutrients and better water holding capacity.

Table 48. Fertilizers equivalency of manure and crop residue at Sadore, Niger, 2003 cropping season.

Parameters	Grain (kg/ha)	Total dry matter (kg/ha)
Absolute control	335	1367
% N in manure	1.6	1.6
% P in manure	0.32	0.32
% N in crop residue	0.71	0.71
% P in crop residue	0.03	0.03
Yield at 2.7t/ha of manure in continuous cropping	775	2419
Yield at 2.7 t/ha of crop residue in continuous cropping	478	1537
Equivalent N and P of the manure	45	29
Equivalent N and P of the crop residue	13	8
Fertilizer N and P equivalency of manure (%)	87	56
Fertilizer N and P equivalency of crop residue (%)	65	40

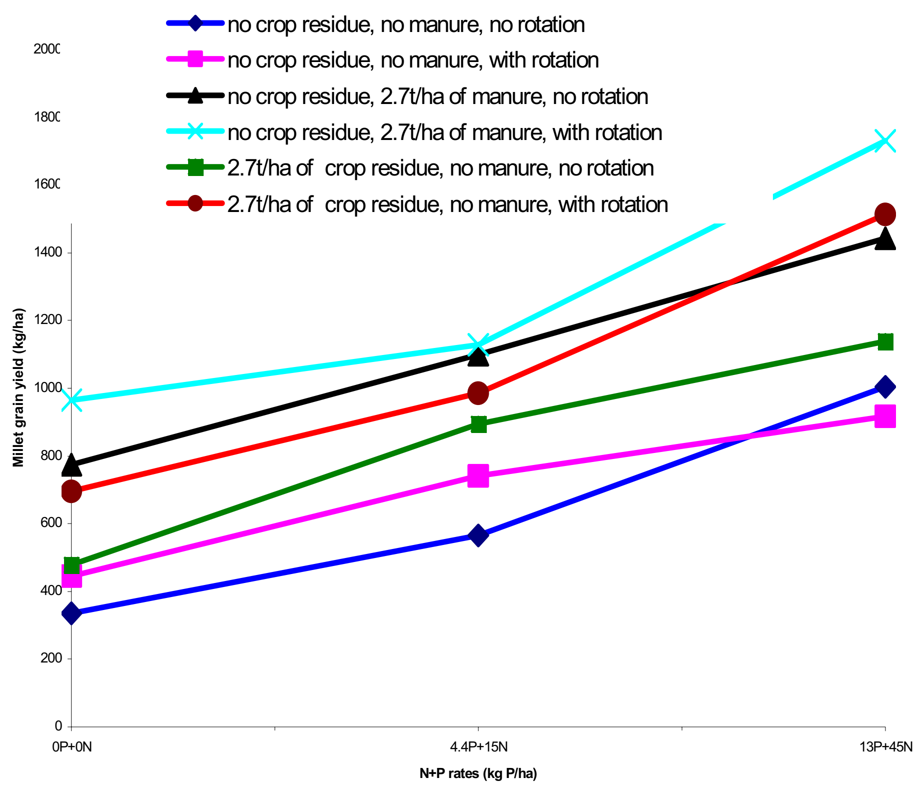

Figure 35: Effect of different N and P rates on pearl millet grain yield, Sadore, Niger, 2003 rainy season.

In addition, the release of nutrient with mineralization over time can match more the plant demand and this will result in higher nutrient use efficiency from the organic amendments. It is also well established that the application of organic amendments can reduce the capacity of the soil to fix P and then increase P availability to plant.

Another crop residue (CR) trial established since 1982 show a large cumulative effect on the soil (organic carbon, protection against erosion…) over these years. Sole application of CR increased the millet grain yield from 253 kg/ha to 833 kg/ha and the millet total dry matter yield from 1865 to 4618 kg/ha (Table 49).

Table 49. Effect of fertilizer and crop residue on pearl millet and cowpea at Sadore, 2003 rainy season

Treatment	Grain yield (kg/ha)		TDM (kg/ha)	
	Millet	Cowpea	Millet	Cowpea
1=Control	253	33	1865	200
2=crop residue (CR)	833	96	4618	1158
3=Fertilizer (F)	568	71	2800	658
4=CR+F	1355	54	7089	1742
SE	96	20	280	132
CV	25%	62%	14%	28%

The data in Table 50 give the rainfall and chemical characteristics at study sites in the Sahel. These soils are acidic and inherently low in nutrients with ECEC of less than 1 c mol/kg for all the sites except Gaya where the organic carbon is slightly higher and an ECEC of 1.3 c mol/kg. The data in Figure 36 on phosphorus sorption isotherm clearly indicated that most of the soils have very low capacity to fix P due to their sandy nature.

Table 50: Annual precipitation (2003) and soil characteristics for selected villages.

Sites	Rainfall Mm	pH KCl	C.org (%)	P-Bray1 (mg/kg)	Ca^{2+} Cmol/kg	ECEC Cmol/kg	N_{min} (mg/kg)
Sadore	534.6	4.3	.12	2.0	0.3	1	3
Banizoumbou	510.4	4.4	.12	1.5	0.4	0.8	5
Karabedji	533.25	4.2	.16	1.9	0.2	0.8	4
Goberi*	450	4.1	.16	1.7	0.2	0.8	2
Gaya	883.5	4.2	.33	2.5	0.4	1.3	9

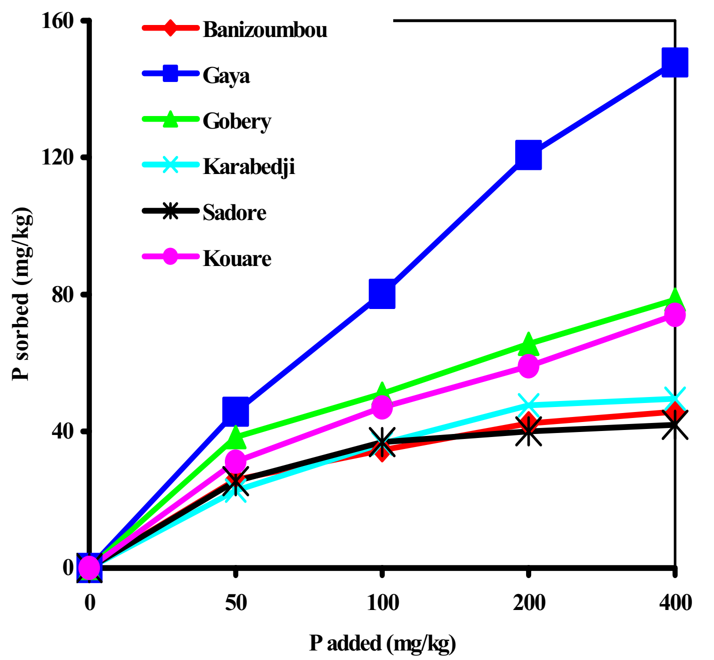

Figure 36. Phosphorus sorption isotherms of soil samples from benchmark sites in Niger and Burkina Faso.

As manure was used in most of the trials in combination with mineral fertilizer, a systematic chemical characterization of the manure used at the different sites was undertaken and the data are reported in Table 51.

Table 51. Characterization for N, P, K and polyphenols of the organics materials used for the trial in each site.

Site	Manure origin	Total N (%)	Total P (%)	Total K (%)	Polyphenols (%)
Banizoumbou	Composite	1.6	0.32	0.75	0.64
Karabedji	Composite	0.26	0.12	0.45	1.02
Gaya	Composite	2.6	0.35	0.80	0.75

Those data will be used to determine the fertilizer equivalencies of different manure sources for nitrogen and phosphorus. The nitrogen and phosphorus levels in the manure were very low and N levels varied from 0.26% to 2.6% and the P levels varied from 0.12% to 0.35%.

TSBFI-Latin America

Completed work

Main factors influencing maize production in the Quesungual agroforestry system in Southern Honduras: An exploratory study

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The objective of this study was to make a systematic description of Quesungual by identifying key factors influencing system performance as well as an assessment of the critical variables influencing maize production. In order to describe the farming system, in which the Quesungual is used, information was collected from 62 farms emphasizing characteristics of the farm household, land use, input use, tree components and farmer perceptions about the benefits they get from this agroforestry system. In a second phase, twenty farms were selected to carry out an analysis of the critical variables affecting maize production in Quesungual fields. In order to select these study farms, the original 62 farms were classified in terms of farm size and land use. Detailed information regarding farm household characteristics and management with emphasis on maize fields and sampling of soils and mulch, as well as measurements of crop yield, was collected through resource flow maps, transect walks, questionnaires, sampling and direct measurements in the maize fields.

The 62 farms studied had land holdings ranging from 0.35 ha to 18 ha. Farmers in the area have limited education, with 1 to 4 years of primary school, and a few never had access to any kind of formal education. The majority of the farmers in the sample have low wealth levels (55%). Forty seven percent (47%) of farmers worked with extension services and 50% had access to credit. The credit is used for buying fertilisers and herbicides. Off-farm work as labourers in other farms is the main source of income. The main agricultural activity in the area is the production of maize, beans and sorghum. Other crops such as coffee, sugarcane, and banana are also planted in limited quantities. Cattle ranching is also an important activity specially at lower altitudes of the study region. Input use is diverse and dependent on resource endowment as well as on perceptions regarding soil fertility. At farm level, 84% of the farmers used fertilisers (urea + compound fertiliser) for basic grain production. Seventy nine percent of the farmers reported using herbicides, and 43% of the farmers used insecticides. Nevertheless, none of the farmers used fungicides. External input use is generally restricted to maize crops and to a lesser extent to bean crops. Nevretheles, insecticides are almost exclusively used for bean production due to pest problems. Almost no inputs are applied to sorghum fields. The role of cattle on nutrient management is generally not consciously recognised by farmers.

Management of Quesungual fields regarding the tree component is influenced by several factors: i) original abundance of trees in the secondary forest at the moment of pruning and conversion to QSMAS, ii) the farmers' local knowledge and iii) the production objectives. Secondary forest tree diversity is reduced following pruning as well as death of some trees unable to tolerate repeated pruning. There is strong preference for timber species especially in the case of timber trees and the naturally regenerating tree categories. In fact, the most abundant species is the timber tree Cordia alliodora, representing 22% of the total frecuency. The remaining species are mainly used as Pruned trees. Pruned trees dominate the tree component because of their high density and consist mainly of weedy species. Timber tree densities had a mean of 304 ± 31 trees ha^{-1}, ranging from 18 to 1503 trees ha^{-1}. Mean densities of Pruned trees are 877 ± 55 trees ha^{-1}, although the range varying between 141 trees ha^{-1} up to 2,405 trees ha^{-1}. Naturally regenerating trees densities at field level are 232 trees ha^{-1}, with a wide range from 0 to 867 trees ha^{-1}. (Table 52).Farmer perceptions with respect to the tree component are related to the benefits of the trees rather than negative effects.

In general, soil variables evaluated had limited power to explain yield variability when considered individually as well as in multiple regression. Multiple regression analysis showed that the main factors influencing maize production were altitude at farm location (Figure 37), P fertiliser input (Figure 38) and Timber trees (figure 39), although the later had a negative influence possibly due to competition. The influence of other soil and management factors was less or not statistically significant. However, an analysis of P use efficiency helped to clarify the importance of labour and timing, and how it could be related to farmer resource endowment. Farmers whose labour availability was limited due to shortage or competing activities had low labour inputs or sowing dates far from the optimum, accordingly the efficiencies of P use were low.

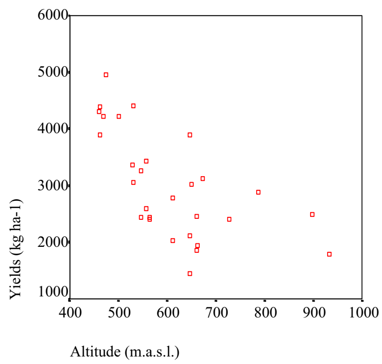

Figure 37. Yields (kg ha^{-1}) of maize, plotted against altitude (meters above sea level), in Quesungual fields in Candelaria, Honduras.
R = -0.63 (p<0.001); N = 29 fields

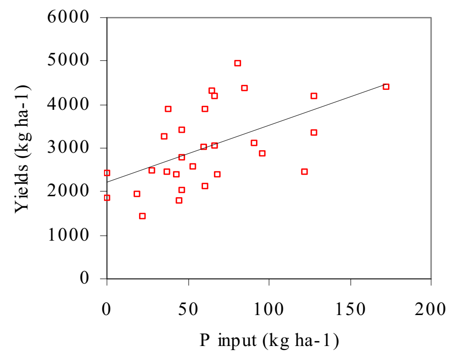

Figure 38. Yields (kg ha^{-1}) of maize and P supplied by fertilisers (kg ha^{-1}) in Quesungual fields in Candelaria, Honduras.
R = 0.55 (p<0.001); N = 29 fields

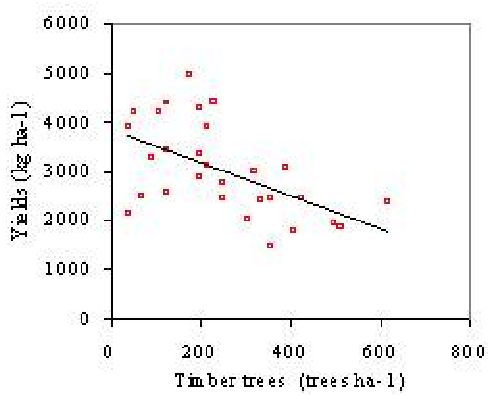

Figure 39. Maize yields (kg ha $^{-1}$) and Timber tree (TT) density (trees ha^{-1}) of Quesungual fields in Candelaria, Honduras. Dashed line shows the maximum tree density at which there is not reduction of maize production.

Farmers adopting the Quesungual system in the sample studied could be divided in two main groups: a) small and medium farms whose main orientation of production is grain for consumption or sale of surplus; b) farms with greater capital and land resources where production is oriented towards cattle production and diversification to other products. However, within these two farmers groups there is variability in the management of maize crops. This subdivision led to a further division generating a total of five farm types, three in the group of small farmers: Farm type 1) income from remittances; Farm type

2) income from off-farm work (agricultural work in other farms); and farm type 3) income derived from off-farm work and sale of grain surplus. Larger farms were divided in two groups: Farm type 4) income derived from cattle and cash crops or sale of small animals, and Farm type 5) income derived from off farm employment (non-agricultural work, for instance carpenters, guards) and cattle. In general the group of small farmers is composed of land holdings smaller than 5 ha, while farm size of the large farms is -oin average 8 ha. Table 52 show the characteristics for each farm type.

This exploratory study of the Quesungual Slash and Mulch Agroforestry System has been important to identify some key factors influencing system performance. It has also been important to help us revise our original research approach and open up many new interesting research questions.

Table 52. Ranges of farm household characteristics, land use, input use, tree component and crop management of the five farm types found in farms at Candelaria. Classes have been defined on the basis of farm size, income generating activities and total income.

	Small farms			**Cattle high income farms**	
Farm type	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	**Farm 5**
N	3	6	4	4	3
Intrinsic factors					
Slope (%)	33 – 73 b	46 – 95	35 – 56	38 – 54	28 –74
Criteria of selection					
Farm size (ha)	2 – 3.5	1 – 3	3 – 6	4 –14	3 – 13
Income generating activities [a]	R, SC & SF	OFW, SP,	R, OFW,	R, OFW,	OFW, CR
Income (lempiras year^{-1})	1590-1700	1490-10838	3190-9848	8080-24936	13200-80000
Farm household					
Family size (# persons)	3 – 8	2 – 11	4 – 7	4 – 9	7- 10
Labour availability (# workers	0.8-1.5	1 – 2.5	1. 4.5	1.5 – 5	1 – 3
Wealth class	Low	low - middle	low - middle	middle -	Middle –
Land Use					
Fallow (% from used land)	12 – 57	0 – 41	17 – 52	1 – 50	27 – 63
Basic grains (% from used land)	38 – 41	46 – 98	35 – 50	19 – 70	12 – 29
Other crops (% from used land)	5 – 19	0 – 17	0 –13	3 – 13	1 – 6
Pastures (% from used land)	-	0 - 25	-	8 – 59	2 – 52
Productivity [b]					
Maize - Milpas (kg grain ha^{-1})	0.1 – 0.4	0.6 – 1.9	1.1 – 2.9	0.7 – 1.4	1.1 – 1.6
Sorghum – Milpas (kg grain ha^{-1})	0.5 – 1.2	0.5 – 1.7	0.3 – 1.2	0.4 – 1.3	
Bean fields (kg grain ha^{-1})	0.1 – 0.4	0.4 – 1	0.1 – 0.4	0.3 – 0.9	0.3 – 0.5
Total bulk production[c] (kg farm)	1.7 – 2.5	1.8 – 2.9	1.9 – 4.6	2.2 – 3.9	1.5 – 2.1
Management factors					
Labour input (person-day ha^{-1})[d]	67 – 131	47 – 145	89 – 124	44 – 101	69 – 97
N input (kg N ha^{-1})[d]	60 – 257	19 – 120	96 – 159	72 – 123	50 – 196
P input (kg P_2O_5 ha^{-1})[d]	28 – 128	19 – 81	36 – 119	21 – 96	68 – 128
Herbicide input (kg a.i. ha^{-1})[d]	1.1 – 7.2	0.9 – 6.6	0.9 – 4.3	0.6 – 2.7	0.9 – 2.4
Sowing date (coefficient)[f]	0.09 – 0.59	0.09 – 2.12	0.34 – 0.77	0.09 – 1.26	0.09 – 1.26
Plant density –maize (plants ha^{-1})[e]	22200-34000	29300-42100	32900-42200	28200-46200	35000-42600
Quesungual factors					
Mulch (kg DM ha^{-1}) [e]	9.6 – 10.8	6.1 – 15.2	6.6 – 12.4	6.2 – 11.4	6.1 – 12.6

Coverage (%)[e]	58 – 68	37 – 75	48 – 67	51 – 74	51 – 72
Natural Regeneration (trees ha^{-1})	18 – 71	106 – 460	159 – 336	0 – 230	124 – 601
Pruned Trees (trees ha^{-1})	1132 – 1609	637 – 1698	637 – 1353	336 – 1574	141 – 1415
Timber Trees (trees ha^{-1})	71 – 318	141 – 495	168 – 309	53 – 292	195 – 619
Productivity					
Yield (g $plant^{-1}$)	98 – 124	51 – 129	88 – 117	51 – 98	66 – 96
Yield (kg ha^{-1})	2.5 – 4.2	1.8 – 5	2.9 – 4.3	1.4 – 4.2	2.4 – 3.4

a Income generating activities are put in order of importance for each farm type (R = remittances, SC = Sells of chickens, SP = Sells of pigs,
SBG = Sell of basic grains, SF = Sells of fruits, SOC = Sells of other crops, OFW = Off farm work & CR = Cattle raising)
b Data based on farmers estimates reported on the resource flow maps during interviews
c Total production includes yields of basic grains, and other crops like coffee, sugar cane, and pumpkins
d Data from resource flow maps (questionnaires)
e Data from sampling during the visits to the farmers (based on measurements)
f Coefficient expressed in standard deviations from the mean sowing date, starting from the beginning of may.

Adoption of new soil conservation technologies in the llanos of Colombia: Arable layer building technology

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As a result of CIAT's collaborative research activities with Corpoica, Pronatta and Unillanos, with financial support from MADR and COLCIENCIAS, a series of soil improvement and conservation practices are available. These practices focus on arable layer building technologies —part of the soil profile that can be modified through a combination of biological and physical management— in soils of the savannas of the Llanos of Colombia. These practices include use of proper crop and pasture rotations in agropastoral systems.

In August 2004, a rapid survey was conducted in order to learn about the adoption of the arable layer building technology (Capa Arable) in farms located in the area of Puerto López - Puerto Gaitán in the llanos of Colombia.

In total, 18 farmers were interviewed, including those that were using and not using the technology. The survey was done using the methodology of semi-structured interviews to groups of producers, technicians and experts of the region, to identify and understand trends and main features of the adoption process.

Results of this survey make reference to technology adoption in early phases, since the first farmers adopted it 4 years ago and the majority of them started adopting it between 1 and 2 years ago. In Table 53 we summarize the main results obtained in the survey and we discuss the major findings.

In general, producers showed great interest in maintaining and improving soils quality, since this practice has a high and rapid payoff in terms of crops and pastures yield. Farmers in the past attempted to establish crops without adequate soils management and used non- adapted pasture and crop germplasm, and consequently experienced large economical failures. In contrast to the previous experiences, utilization of soil conservation methodologies together with the use of improved germplasm have shown significant advantages in productivity and in economic returns to the investments made.

Table 53. Results of the survey on the use of the arable ayer building technology by oproducers in the llanos of Colombia.

Variable	Level
Number of producers interviewed	18
Land Use	
Total Area of farms (ha)	
Mean	883
Range	120-5000
Area under crops (ha)	
Mean	238
Range	0-1100
Area under pastures and other uses (ha)	
Mean	645
Range	0-3900
Area under crops/Total Area (%)	27
Proportion of producers with no crops (%)	28
Most common rotation	Maize-soybean
Most common land preparation method	Vertical tillage with chisel plow

Practices for arable layer building include a vertical corrective tillage using rigid chisels, correction of nutrient deficiencies in soil and sowing of forages and acid soil adapted crops. In some cases, lack of key inputs such as machinery, fertilizers and seeds prevents establishment of crops or timely harvest of crops, which has negative implications for building arable layer and for the economics of the system. There is great interest from the Colombian government and also from the private sector (e.g., poultry) in emphasizing grain production in the savannas of the llanos of Colombia. Some field crops are being established in the farms of poultry farmers to improve feed production in the region. Thus the expansion of field crops in the region is beeing pushed by the poultry sector.

The most frequent rotation is maize in the first semester and soybean in the second. The new rice variety, Line 30, recommended in this technology and that has not been commercially released yet is creating great expectation among farmers due to its high productive potential.

Even though there is clear conscience among producers of the fact that continuous monoculture degrades the soils and provokes greater pest and disease pressure, price variations in crops seem to drive the rotation cycles. High price expectations for soybean in 2004 induced many producers to plant this crop in both semesters.

Many of the farmers that have introduced crops in their farms traditionally have been and continue to be livestock producers. The majority of these farmers interviewed said that they are working with crops to improve soils and to subsequently sow high productivity pastures. Thus it seems that there will be a high demand for new forage cultivars that are being developed by CIAT Tropical Forages Project, as is the case of the new Brachiaria hybrids such as Mulato already in the market.

Productivity gains constitute the principal benefit perceived by those who apply soil conservation practices in the well -drained savannas of the llanos. In general, yields in the first sowing are low, but increase subsequently as a result of soil improvement. With soybean, initial yields are between 1,5 and 1.9 t/ha, and in rare cases reaches 3t/ha. With maize, yields are between 4 to 5 t/ha. It is foreseen that over time crop yields will begin to decline and when this occurs it will be the time to introduce pastures in the rotation.

Since the introduction of crops is new in the Llanos, most farmers interviewed do not have enough clarity on the duration of the crop phase and pasture phase of the rotation. Several of the farmers interviewed consider that between 4 and 5 years of crop rotations is needed before reconverting the land to pastures; other farmers estimate that changing crops to pastures will occur when productivity of the crop starts to decline as a result of soil fertility loss.

Constraints for adopting the arable layer building technology are economic in nature and lack of infrastructure.

Some of the economical constraints have to do with:

1. Low availability of capital associated with inappropriate credit plans.
2. Market price fluctuations of products that generate large income variations.
3. Eventual oversupply of products such as rice, and
4. High cost of inputs and agricultural machinery.

In terms of infrastucture the following limitations were mentioned:

a) Poor roads that increase cost of transportation, and

b) Low quality of seeds sold in the market that results in poor yields and reduced income.

Those farmers who have not introduced crops in their farms mentioned various reasons for not having done so:

a) Land shortage, which is something critical in small properties that do not have sufficient areas to establish crops.
b) Lack of capital and machinery to start agricultural activities.
c) Lack of experience in agriculture.
d) Time shortage or little desire to invest additional time to crops, and
e) Farm topography that does not permit crop establishment.

In summary, our survey indicates that the most immediate impact area for the arable layer building technology developed by CIAT is the Puerto López – Puerto Gaitán region, approximately 180 thousand hectares. It is considered that for its rapid adoption, investment by the Colombian government in improving road infrastructure is critical. In addition, in the more remote areas of the llanos there are a number of other critical factors (i.e. lack of machinery, inputs, technical assistance, qualified hand labor and roads and communications) that prevent the introduction of crops to establish rotations with pastures in sustainable agropastoral systems.

5.2 Development and validation of soil biological indicators of agro ecosystem health.

TSBFI-Africa

Completed Work

The role of indigenous knowledge in the management of soil fertility among smallholder farmers of Emuhaya division, Vihiga district. (MA thesis defended)

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The knowledge of local soils possessed by smallholder farmers was found to be elaborate. Knowledge of local soil was responsible for the naming, differentiation and classification of soils. The study also shows that farmers understand different processes that occur on their farms. They were, therefore, not only able to identify different landscapes but also recognize different niches.

Farmers also acknowledge that some of these niches, such as the home gardens, are as a result of human action while some, like valley bottoms and eroded surfaces, *esilangalangwe,* were a result of natural process. What is more, farmers understand that these natural processes can be facilitated by the action of farmers. The study has shown that farmers are familiar with the various soil types in their locations. This confirms the first assumption of the study that farmers have local diagnostic criteria for classifying soils. As discussed above, this study also confirms findings among farmers in other countries.

According to information obtained in this study, the local knowledge of soils is learnt through a number of sources, mainly experience and observation. The other sources mentioned include elderly farmers as well as parents. The role of scientist and researchers in the gathering and dissemination of this local knowledge of soils was also acknowledged. The implication here is that in addition to the farmers' indigenous knowledge, scientific knowledge is also needed for sustainable smallholder farming.

Because of the broad nature of their knowledge of local soils, farmers also have an indigenous criterion for diagnosing the soil nutrient status. It was observed that smallholders have a variety of ways which they employ to interpret the fertility status of the soils in their farms. Soil fertility, which is an invisible constituent of soil, is interpreted through soil characteristics such as colour, texture, depth and location. Farmers also diagnose soil nutrient status through plant and crop performances. This study also found that there are certain specific plant and animal species associated with different soil conditions. This seems to confirm the second assumption of the study that the situational status of soil fertility can be diagnosed through the observation of certain specific indicators. It was further learnt that the action taken by a farmer when the signs for soil nutrient depletion is witnessed depends largely on the type of the indicator. Diagnosing the situational status of the farm nutrient is, therefore, part of the wider repertoire of local agricultural knowledge.

Households within the study area were found to be engulfed in the crisis of poverty and this, coupled with the process of socio-cultural and economic change, was found to be a constraint to smallholders' efforts to manage the fertility of their croplands. The sizes of the family landholdings are gradually declining as the number of livestock owned by households also decline as a result of the social, demographic, cultural and economic transformations that are taking place in contemporary Kenya. These changes, to a greater extent, have profoundly altered the farming system and introduced landscapes that were unknown to the Abanyore. In general terms, smallholders' households were found to be undertaking certain strategies to support the management of their landscapes and croplands. However, it was also observed that smallholder farmers face a number of constraints in their effort to manage the fertility of soils. As reported here, indigenous soil management strategies that still survive have been overstretched and will require external support in terms of repacking if they are to be of any help to smallholders' needs. Largely because of these constraints and partly because of the nature of poor resource farmers, the responsive behaviour to soil nutrient depletion sometimes is not determined by the type of infertility indicator observed.

This study has revealed that farmers varied input use, crop choices and cultivation, depending on the niche type. For instance, no farmer reported the use of inorganic fertilizers in the home gardens. On the other hand, food production, income and labour, guided the farmers' management decision. The above argument partly confirms and partly disapproves the third assumption of the study that farmers' responsive behaviour to soil nutrient depletion depends on their cognitive view of soil fertility indicators. Data collected throughout the study reveal an existence of both indigenous and modern strategies of soil nutrient management within the study population that can be effectively manipulated to address the problems faced by smallholder farmers in the study area in managing the fertility of their soils. However, these strategies are not effectively dealing with the problem of soil nutrient depletion mainly due to the many changes identified above. Part of this inefficiency can be attributed to the varied number of constraints that farmers face in their effort to apply these strategies to their fields.

The soil fertility management practices adopted by farmers are mainly perceived as efforts meant to increase yield. Farmers prefer inputs that are relatively cheap, need considerably less labour to apply and benefit particular crops in the shortest time possible. Therefore, while farmers acknowledge that different soil types require different management strategies, some practices are crop specific or appear to be associated with a particular set of crops. However, farmers and the general community did not have an alternative strategy that could help smallholders improve crop productivity. In fact, key informants seemed to support the coping mechanisms widely used by farmers despite the fact that they were widely aware of the constraints faced by them in using these strategies. One can, therefore, not avoid concluding that crop productivity among smallholder farmers of Emuhaya seems to have no option but the enhanced management of the soils. Integration of farm nutrient management is the only sure way to enhance productivity on farmers' fields. This inevitably calls for the integration of knowledge systems (modern and indigenous).

Recommendations for Policy Makers and Implementers

- Policies designed to address the soil fertility management problems smallholders face should not look at farming in isolation. For such policies to be affective, and to be closely linked to the needs of smallholder farmers, they need to take into consideration the farmers' folk knowledge which incorporates both environmental and ecological aspects.
- Non-governmental organizations and research institutions working in the area should educate smallholders on the need to manage local soils appropriately. This should be done through helping the farmers to mobilize resources and start income-generating activities that would relieve poor families of the overwhelming constraints they face. In all initiatives designed to assist farmers, they should be made to take an active role, and their folk perspective in farming respected. This would facilitate acceptability and, may be, the long term sustainability of such initiatives.

On-going work

Scientific assessment of farmers' perceptions of soil quality indicators within smallholder farms in the central highlands of Kenya

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A study was conducted to determine farmers' perceptions of soil quality and common soil management practices that influenced soil fertility within farmers' fields in Chuka and Gachoka divisions, Kenya. Soils were characterized by farmers after which they were geo-referenced and sampled at surface depth (0–20 cm) for subsequent physical and chemical analyses, to determine differences within farmers' soil quality categories. Special attention was given to agricultural weed species. Indicators for distinguishing productive and non-productive fields included crop yield and performance, soil colour and soil texture. A total of 18 weed species were used to distinguish between high and low soil categories. There were significant differences among soil fertility categories, using parametric techniques (ANOVA) for key soil properties ($p < 0.005$), implying that there was a qualitative difference in the soils that were chacterised as different by farmers. Fertile soils had significantly higher pH, total organic carbon and exchangeable cations, with available-N being significantly different in Gachoka. Soil fertility and crop management practices that were investigated indicated that farmers understood and consequently utilized spatial heterogeneity and temporal variability in soil quality status within their farms as a resource to maintain or enhance agricultural productivity.

This study was conducted on a sample population of 60 farmers in the 2003 long rain season, to determine their' perceptions of soil fertility and common soil management practices which influenced soil quality within farmers' fields in Chuka and Gachoka divisions, which fall in Meru South and Mbeere Districts respectively. Farmers were asked to identify soil fertility indicators that they used to determine fertility status of their soils in the productive or non-productive fields within their farms.

Farm selection for the study was done randomly in pre-selected sub–locations (Kirege and Gachoka sub–locations) in Chuka and Gachoka Divisions respectively. A list of villages was first obtained from divisional offices to constitute the sampling frame, from which the study farms were randomly selected. Social data was collected first from all farms (60), after which top soils were sampled from both productive and non-productive plots within smallholdings in both divisions. Soil sampling was then conducted on fifteen farms selected in both divisions from the farms that were visited in the household survey. In each village, two farms were then selected and sampled for topsoils (0-20cm). Soils were recovered by compositing, from a minimum of 10 randomly selected sites on farmers' fields. Lastly, half kilo (500g) subsamples were sealed and transported in cool boxes for laboratory analysis. In the laboratory, soils from the two divisions were were logged in and analysed separate batches (there were a total of two batches).

Soil chemical parameters that were determined included soil reaction (pH), exchangeable acidity, exchangeable bases (Ca and Mg), extractable phosphorus (Olsen), total organic carbon, available nitrogen, total nitrogen and total phosphorous, while physical parameters included soil texture and water aggregate stability. Routine methods outlined in the Tropical Soil Biology and Fertility manual were used to analyze soils. Throughout the chemical analyses, samples were randomly replicated within the batches for quality monitoring.

Results showed that farmers only used sensory information (soil tactile and visible characteristics) to distinguish within soil fertility categories. The most important indicators for characterising productive and non-productive fields included crop yield (86%) and performance (76%), soil colour (60%) and soil texture (40%) in Chuka division while in Gachoka, soil colour was the most important indicator (84%). A total of 18 indicator plant species were used to distinguish soil fertility status in both divisions.

There were significant statistical differences among soil fertility categories, using parametric techniques (ANOVA) for key soil properties ($p < 0.05$), implying that the soils must have belonged to different populations and that there was a qualitative difference in the soils that were chacterised as different by farmers. In both sites, fertile soils had significantly higher pH ($p<0.001$), total organic carbon and exchangeable calcium ($p<0.001$), and magnesium ($p< 0.05$). Available-N was also significantly higher in fields rated as fertile in Gachoka division, but not within fields in Chuka division (Table 54).

Table 54: Soil chemical properties from high and low fertility sites in Chuka and Gachoka divisions.

Soil Quality Category	Total N	Total P	C	N	P	Ca	Mg	PH
	%			$mgkg^{-1}$			$cmol_c\ kg^{-1}$	
Chuka								
High	0.16a	0.05a	33.6a	2.74a	20.5a	8.2a	3.1a	5.6a
Low	0.16a	0.05a	24.3b	2.79a	16.0a	7.5a	2.8b	5.1b
SED	0.02	0.01	3.99	0.16	4.27	0.65	0.12	0.08
Gachoka								
High	0.16a	0.05a	15.2a	2.43a	17.8a	5.8a	1.8a	6.5a
Low	0.02a	0.05a	12.5b	1.40b	6.2a	3.8b	1.3b	6.4b
SED	0.18	0.01	0.18	0.21	7.27	0.48	0.15	0.09

The productive soils showed a higher pH ($p<0.001$) and exchangeable cations than non-productive soils in both divisions. Exchangeable cations also varied significantly for Mg ($p<0.05$) in both divisions, while Ca ($p<0.001$) was only significantly different within sites in Gachoka division. Comparing pH and exchangeable bases between sites, it was observed that overall, they were higher in Gachoka, which due to less rainfall, is semi-arid as compared to humid conditions in Chuka division.

In conclusion, soil fertility and crop management practices that were investigated indicated that farmers understood and consequently utilized spatial heterogeneity and temporal variability in soil quality status within their farms as a resource to maintain or enhance agricultural productivity.

TSBFI-Latin America

Completed work

Evaluating soil quality in tropical agroecosystems of Colombia using NIRS

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In order to evaluate the impact of agricultural development models on the quality and health of the soil, it is necessary to monitor the physical, chemical and biological quality of the soil precisely, using sensitive and efficient techniques that make it possible to detect significant changes in the condition of the same. Near Infrared Reflectance Spectroscopy (NIRS) analysis makes it possible to evaluate soil characteristics related to organic matter (OM) including carbon, nitrogen, phosphorus, moisture content, cation exchange capacity, clay content and $CaCO_3$, among others. This technique has been widely used for several decades to determine the moisture content in seeds, determination of dry matter and crude proteincontents, the state of decomposition of dead leaves, C, N and P contents in plant material, sugar content in fruits and to identify or characterize polymers, pharmaceutical, petrochemical and other industry products. While it has been shown that it is possible to measure moisture, OM and total N contents simultaneously, using NIRS. The prediction is relatively poor, however, when the concentrations of C and total N are relatively low (C <0.3% and N <0.03%) and in soils with a broad range of colours. In addition, studies in Australia have shown that the cation exchange capacity, the exchangeable Ca and Mg, the Ca:Mg ratio, organic C, and percent exchangeable sodium and aluminium were adequately predicted by NIRS at specific agricultural sites. Shepherd and Walsh (2002) developed a scheme that makes it possible to use a library of spectra of soils from eastern and southern Africa to estimate, quickly and non-destructively, certain soil properties such as Ca, Mg, K and exchangeable P, organic C, pH, potential mineralization of N, effective cation exchange capacity, and particle size and distribution, based on diffuse reflectance spectroscopy analysis.

The application of NIRS in soil analyses has generally focused on the prediction of some of its properties through calibration and validation, and the main interest on simplifying this analysis vis-à-vis the traditional chemical methods. Nevertheless, the potential of NIRS as a technique capable of separating soils submitted to different agricultural uses and diagnosing its quality has not been exploited. The purpose of this work was to assess the capacity of the NIRS for evaluating soil quality, as reflected in its OM contents and composition, and in some chemical and biological properties.

Near infrared reflectance spectroscopy (NIRS) analysis was used to distinguish among soils of different agroecosystems in Colombia, based on differences in quality and quantity of organic matter and in certain chemical and biological properties (Table 55).

Table 55. NIRS wavelength values (nm) characteristic of the soil-use systems.

Wavelengths (nm)	Soil-Use System*
400-560	CP
580-740; 1220-1420	ERO, DPG
760-1200; 1900-2220	FWL, CPS
1440-1880; 2240-2400	SF, PAS, CPS

* CP = coffee plantation, CPS = coffee plantation under shade, DPG = degraded pasture with grazing, FWL = fallow in water-logged zone, PAS = ungrazed pasture, ERO = soil-eroded plot without vegetation. FAC = 1-year fallow after intensive cassava crop, SF = secondary forest

A correlation was sought between the wavelengths determined by NIRS and certain chemical properties of the soil (Ca, Mg, K, Al, total P, $N\text{-}NO^-_3$, P-Bray II, $N\text{-}NH^+_4$), the percentage of carbon content in different fractions separated by size and density (LUDOX), and microbial activity measured by respirometry in the laboratory.

The variables evaluated were grouped into three classes: (i) chemical variables (Ca, Mg, K, exchangeable Al, total P, P-Bray II), (ii) organic variables (total C, total N, $N\text{-}NH^+_4$, $N\text{-}NO^-_3$, respirometry and organic matter fractionation) and (iii) NIRS variables (101 variables given by the absorptions in the near infrared region). For each group of variables, a principal component análisis

(PCA), together with discriminant analysis, was run. Each group of variables separated the different soil-use systems (***P <0.001) similarly. Afterwards, co-inertia analyses among the different groups of variables verified the sensitivity of the NIRS in detecting significant changes in the soil chemical and organic composition, as well as in microbial activity (Table 56).

Table 56. Results of the multivariate analyses run using NIRS data, chemical, OM related variables.

	PCA[b]		**Discriminant Analysis**		**Analysis of Co-Inertia**			**Statistical Significance**[c]
Variables	**Factor (%)**		**Factor (%)**		**Variables**	**Factor (%)**		
	1	2	1	2		1	2	
NIRS 240	38.5	30.8	48.15	33.5				
NIRS 50	45.82	31.58	56.38	31	NIRS/OM	67.49	23.67	P <0.001
Chemical	47.25	27.67	59.26	24.67	NIRS/Chemical	65.55	30.74	P <0.001
OM[a]	38.66	23.86	48.13	23.86	Chemical/OM	86.21	8.14	P <0.001

[a]OM= Organic matter
[b]PCA+ Principal Component Analysis
[c]Statistical significance same for all multivariate analyses

These results show the high potential of NIRS for evaluating soil quality in large areas, rapidly, reliably and economically, thereby facilitating decision-making with respect to soil management and conservation.

5.3 Develop working approaches towards collective action to arrest land degradation (e.g. gully stabilization)

5.4 Development of cross-scale practices for management of soil biota-mediated agro ecosystem services.

5.5 Trade-offs/win-win situations between agricultural productivity and ecosystem service provision evaluated.

TSBFI-Africa

On-going Work

Relationships between organic resource quality and the quantity/quality of the soil organic matter pool
H Wangechi and B Vanlauwe
See report on activity 1.1.
TSBFI-Latin America

On-going work

Payment for environmental services in the Fuquene watershed (Colombia): Physical parameters, carbon stocks and fluxes of greenhouse gases
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CAR

The Water and food challenge program approved to CONDESAN a project to pursue the "Payment from environmental services as a mechanism to promote rural development in the upper watersheds of the tropics". Environmental services considered include the provision of water, biodiversity conservation, prevention of soil erosion and potential for mitigation of net emission of greenhouse gases (GHG) and carbon sequestration. The project will operate in a group of nine pilot watersheds in various Andean countries. The Fuquene Watershed in the central part of Colombia, near Bogotá, was selected to initiate the project and to test methodologies that later will be used in the assessment of the other watersheds. The Fuquene lagoon collects the water from the watershed and provides water to a vast number of villages and agricultural fields in neighboring areas. Despite numerous governmental, bilateral and private projects that have operated in the watershed, the lagoon, suffers an accelerated rate of reduction in area/water volume as well as eutrophication, due to several factors including border land recovery by ranchers, pollution of incoming water with sewage sludge, animal manure and nutrients leached from fertilizers etc. The watershed covers an area of 187,000 ha. Main production activity in the watershed is intensive cattle raising. The most productive dairy farms in Colombia are likely located in this region. Total area covered by pastures (mainly Kikuyo grass in the lower basin and Ryegrass in the medium to upper part) is 110000 ha (59% of the area). Potato is the main crop in the watershed and is usually managed with conventional tillage, which involves major soil disturbance which promotes soil erosion and nutrient leaching. Total area under crops is around 48000 ha (26% of the area). In recent years as a result of activities from a GTZ project, no tillage systems have been promoted and are slowly gaining acceptance by potato growers. There are some 2000 ha of no till potato now in the watershed.

Our contribution to this project will make a quantification of the status of the most important soil physical characteristics that regulate soil function in relation to water, nutrient storage and leaching. We will also assess total carbon stocks in soils and biomass as well as net fluxes of carbon dioxide, methane and nitrous oxide in the watershed and also will quantify C stocks and GHG for the dominant land use systems. The purpose is to identify the land use systems that are more beneficial or detrimental to the environment. This information will be contrasted with information on sustainability of land use and the socioeconomic of main production systems collected by other researchers as part of the project. Win- win systems could then be promoted to help policy makers and local authorities to reorder land use in the watershed to maximize benefits for local farmers and communities as well as for neighboring receivers of water and services and for the global environment.

Seven dominant land use systems on similar soils (hydrologic response units-HRU) were selected to fall within four transects: one longitudinal transect crossing the watershed from south to north and three perpendicular transects distributed along the main axes to spread along the watershed. Selected HRU included: Paramo native vegetation, mountain secondary forest, potato crops under conventional and no tillage, Ryegrass pastures, Kikuyo intensively managed pastures, and degraded land that not longer supports productive uses. These HRU were replicated three times trying to cover the spatial variability found in the watershed. A total of 21 sampling plots were selected.

Soil C stocks: In each of the 21 plots, three soil pitches (0.5 × 0.5 × 1m) were open: Pitches were located at three altitudinal position within each plot. Upper part, medium and lower part of the plots. In each pitch, composite soil samples were collected at four depths (0-5, 5-20, 20-40, and 40-100) to measure bulk density and determine total Carbon stocks in soils. Soil samples will be analyzed using conventional wet oxidation methods to assess oxidable carbon and by CHN analyzers to measure total carbon. In areas where the history of land conversion from C3 type dominated vegetation (i.e native forest) to C4 dominated species (some grasses, maize, sorghum etc), or from C4 into C3 vegetation, is well known and reliable, ^{13}C determinations will be made in soil samples to assess the rate of replacement of new organic matter and to establish C partitioning between soil pools of different mean residence times.

Soil Physical parameters: At the time of soil sampling some soil physical characteristics were evaluated in situ: resistance to penetration in the soil profile using a penetrograph and soil shear strength (torcometer). Samples were collected for bulk and particle density determinations measuring saturated hydraulic conductivity, air permeability, resistance to compaction, and water retention characteristics. As physical condition define how water can be store and move into the soil profile, a good understanding of the behavior of the physical soil profile in relation to water fluxes will allow to define if there are possibilities of contamination with elements coming from fertilizers or not. As also they define, the hydrologic response of the soil in relation to rainfall, they will allow to understand the relationship between rainfall and rainfall acceptance capacity of the soils, runoff production as well as the vulnerability of soils to be eroded. This knowledge will help to track sources of contamination of the lagoon and the loss of the water mirror and will be used to define solutions to control degradation problems.

Carbon in plant biomass will be done through allometric equations for trees and shrubs and by harvesting representative subplots of crops and pastures. Allometric equations will be developed for selected species when not available.

Greenhouse gases: Fluxes of carbon dioxide, methane and nitrous oxide, the three most important GHG related to land use change and agricultural activities, are being monitored on an annual basis to follow at least a full cycle of climatic variations. One of the replications for the seven HRU was selected for monitoring gases. In each plot four replicate sampling points were selected and georeferenced. A PVC collar (30 cm diameter, 10 cm height) was permanently installed in the soil to a depth of 8 cm. A closed vented chamber is attached to the collar at the time of gas collection. Four gas samples are collected per chamber at times 0, 10, 20 and 30 minutes. Chamber temperature is measured at every sampling time. A biweekly sampling frequency is used. Gas samples are stored in pre-evacuated glass vials and are analyzed within two weeks after collection by gas chromatography (ECD and FID detectors) for CH_4, CO_2 and N_2O. Gravimetric soil water content is measured at every sampling time. Soil redox potential, pH and soil temperature is measured in situ and soil samples are collected periodically for monitoring ammonium and nitrate levels.

Integration of annual fluxes of both C and GHG will be done at the watershed level by using similar hydrologic response units and adding them using land cover data from remote sensing and GIS techniques. Once annual data is collected and the global warming potential of different HUR is calculated, a modeling process could be conducted to estimate how the reordering of land use systems in the watershed will influence the interaction with the environment.

Figure 40 shows partial data on soil shear strength for the dominant land uses found in the watershed. Data for one of the replicates is showed. The paramo sites show values of shear strength above the threshold value (60 kPa) considered as acceptable for plant growth. This is an indication of surface soil hardness even under natural condition and explain why farmers have to use tillage to overcome this limitation. No tillage systems clearly reduce surface soil strength favoring the developing of the root systems. Intensively managed pastures have resulted in very high surface strength, likely as a result of cattle trampling. Degraded soils showed the most extreme levels of soil compaction. This will surely, root establishment preventing any productive use of the soil under current conditions. Land rehabilitation strategies should be implemented to reduce these limitations to tolerable levels that allow plant growth. Soils under no tillage crops exhibit an adequate physical environment for root development.

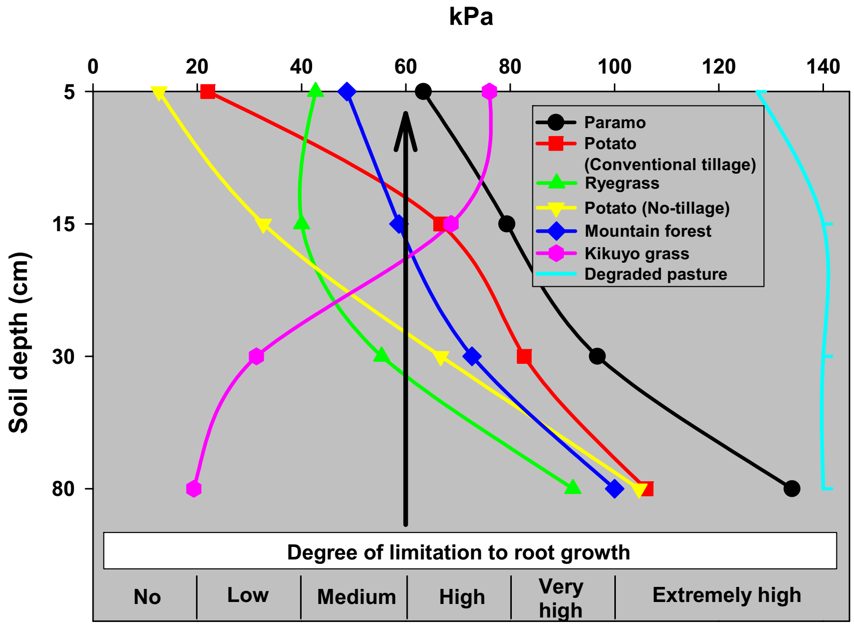

Figure 40. Soil shear strength for diverse land use systems on the upper Fuquene watershed (Colombia)

5.6 Integration of plot-farm-watershed and higher-level information related to the target ecosystem services across scales.

5.7 Local and formal monitoring systems to evaluate the impacts of ISFM options and other land management practices on ecosystem services developed.

5.8 Develop or identify systems that contribute to C sequestration and mitigate greenhouse gas emission

Completed Work

Carbon Sequestration Potential of the Savannas (Llanos) of Colombia and Venezuela

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Neotropical savannas of Latin America represent one of the last frontiers where agriculture could be expanded in the world. These savannas are located in Brazil (204 Mha), Venezuela (25 Mha), Colombia (23 Mha), Bolivia (13 Mha) and Guyana (4 Mha). Savannas in Colombia and Venezuela are called Llanos (flatlands) and constitute a continuous and relatively homogeneous system of nearly 50 Mha. Soils in the Llanos are dominated by very acid oxisols, low in natural fertility and high in aluminum saturation, which prevent good performance of non adapted species. Soil are considered fragile and very susceptible to degradation. Intensive tillage operations have resulted in serious loss of physical stability. In the last three decades, government programs have promoted the expansion of agriculture and livestock in the

Llanos, particularly in Venezuela. Expansion of pastures in Latinamerica was triggered by the introduction and improvement of grasses coming from Africa, particularly *Brachiaria* species. Pioneering studies at CIAT done in the Colombian Savannas showed that these deep rooted grasses are able to increase soil organic content in the soil at rates ranging from 1 to 3 Mg $C.ha^{-1}y$-1. Our own subsequent studies found that conversion of tropical savannas into pastures or even cropland with appropriate management could result in a net decrease in net fluxes of various greenhouse gases from the land into the atmosphere and could generate net carbon equivalent gains. Tropical agroecosystems have an intrinsically high net primary productivity and are consequently of interest by their high potential to sequester atmospheric carbon , that could be traded trough the CDM or similar mechanisms to compensate emissions reductions that developed countries are unable to fulfill internally. We made an attempt to estimate the total carbon storage in soils from the Llanos under current land use system and to estimate the maximum potential of the region to capture atmospheric carbon in soils and finally to make an estimate of the range of feasible carbon accumulation that could be expected in the region in the coming two decades given the development plans foreseen for the region.

We made a comprehensive literature review of available information in both Colombia and Venezuela, relative to soil carbon levels and stock in different subregions, natural land cover, crops, cropping systems, forest plantations etc. The Llanos were grouped in a set of various subunits corresponding to the dominant landscape positions having relatively homogeneous soil conditions. Recent land cover was generated for this study using satellite images. For Colombian Llanos, a recent soil survey from the National geographic institute including more than 500 sampling sites across the Llanos which include data on soil carbon as well as bulk density was used to estimate carbon stocks. In Table 57, Carbon stocks in soil (0-30 cm depth) are presented for the main landscape positions and land cover found in the Llanos of the two countries.

Despite recent land intensification, the Llanos are still dominated by native vegetation. Land use conversion has been much more accelerated in Venezuela than in Colombia as a result of more infrastructure and development programs at the National level. Carbon content in the soils is not homogeneous among the main landscape positions. There is a west – east gradient of soil carbon with the higher values near the Piedmont from the Andes in the west and the lower values towards the Orinoco floodplain in the east. Similarly gradients in soil bulk density do exist and sand seems to increase from west to east. This is likely the result of millennial continuous movement of sediments and eroded materials from the Andes to the east. There is also a clear gradient in precipitation with the higher annual values (2700mm) in the Andean piedmont to 800 mm in the Orinoco Delta.

Our estimate for total carbon stored in the top 30 cm of soils from the Llanos results in a value of 3.1 Pg C. Different land uses result in different C stocks. Estimated values should be viewed with some caution given the various assumptions in terms of homogeneity of functional subunits and carbon content in soils that we were forced to make to compensate the lack of more precise data.

In this study, the results of a long term experiment in the middle of Colombian llanos (Carimagua research station) confirmed previous findings that the conversion of native savanna vegetation to improved pastures (*Brachiaria humidicola* associated with forage legumes) resulted in net C accumulation in the soil of around 2.5 $MgC.ha^{-1}.y^{-1}$ over an 8 years period. A theoretical conversion of all available land into improved pastures, could potentially result in a net C accrual in soils of about 1.02 Pg of C. Savannas are however unique ecosystems that are host to a high diversity of endemic species of fauna and flora and play important though still poorly known roles in the regional biogeochemical cycles. Therefore it is necessary to balance the Government plans to develop the region with the necessity to preserve adequately sized areas under natural conditions.

Examination of national plans of Colombia and Venezuela to intensify agriculture and livestock in the Llanos in the coming 20 years and analysis of historic trends in land use change suggest that around 5 M ha of new pastures will be added as well as 1 M ha of crops and 1M ha of forest plantations. With these projections, we estimate that approximately 160 TgC can be added to soil C stocks in the next 20 years in the Llanos. Trading of these carbon C capture could potentially result in appreciable resources flowing to the region. However, a great deal of effort is necessary at various levels before this potential could be materialized.

Table 57. Estimated carbon stocks for the main land use systems in the Llanos from Colombia and Venezuela.

Ecoregion	Area (Mha)		Estimated Soil Carbon stocks (0-30 cm depth)			
			Colombia	Venezuela	Colombia	Venezuela
	Colombia	Venezuela	$MgC.ha^{-1}$		Tg C per Land cover	
Remaining Natural systems						
Elevated plateaus	7.29	5.04	73.98	35.66	539.3	179.8
Well drained lowlands	2.51	4.81	83.54	43.16	209.7	207.6
Poorly drained low plains	2.13	5.45	89.92	59.41	191.5	323.8
Rolling hills	6.84	1.66	48.07	40.00	328.8	66.4
Gallery and deciduous forest	2.65	1.52	138.60	75.00	367.3	114.0
Subtotal	*21.42*	*18.48*			*1636.6*	*891.6*
Modified systems						
Introduced pastures	0.98	5.00	98.20	78.00	96.2	390.0
Annual crops-conventional tillage	0.39	0.83	70.49	38.10	27.5	31.6
Annual crops-reduced tillage	0.001	0.17	72.90	43.20	0.07	7.34
Tree plantations	0. 1	0.80	73.39	27.00	7.34	21.6
Urban, water bodies	0.72	0.90			-	-
Subtotal	*2.19*	*7.70*			*131.1*	*450.6*
Total per country					1767.7	1342.2
Total for the Llanos					**3110**	

On-going Work

The TSBFI-LA team will continue its collaboration with the C-sequestration project, supported by the Netherlands Cooperation (Activity CO-010402): "Research network for the evaluation of carbon sequestration capacity of pastures, agro-pastoral and silvo-pastoral systems in the American Tropical forest ecosystem". Its main goal is to contribute to sustainable development, poverty alleviation and mitigation of the undesirable effects of greenhouse gasses on climate change, in particular CO_2. It combines efforts from the National Research Community, represented by CIPAV and Universidad de la Amazonia and the International Research community represented by CIAT, CATIE and Wageningen University and research center.

Under this project two major activities have been done: (i) a chapter for a book edited by R. Lal on potential of C-sequestration in the Andean hillsides, and (ii) an article for Agroforestry Journal on the overview of the project.

5.9 Crop, pasture, fallow, water, and soil management strategies developed to minimize sources and/or increase sinks of GHGs