Output 3. Improved decision making for combating soil degradation and greater agricultural productivity

Activity 3.1 Identify dynamic soil properties and test their suitability as soil quality indicators

3.1.1 Test the suitability of acid-ammonium oxalate extraction method to quantify the available soil phosphorus pool

Highlight:

- Showed that oxalate extracted P or the combined pools of resin + bicarbonate-P of the Hedley fractionation scheme may be better suited to determine soil P availability in oxisols that receive strategic application of lower amounts of fertilizer P.

Purpose:

To compare acid ammonium oxalate extraction method with Bray-II extraction, resin and bicarbinate extraction, and extraction with iron-impregnated paper strips for determining the available P in low-P supplying oxisol.

Rationale:

Phosphorus sorption capacity of highly weathered oxisols is due to P sorption capacity of various oxides, hydroxides, and oxyhydroxides of Fe and Al, and some of these components are active noncrystalline Fe and Al. These active and noncrystalline Fe and Al constituents are important in determining the availability of P in low P supplying oxisols because of their large surface areas and high reactivity with phosphates. Extraction with acid ammonium oxalate in the dark mainly dissolves active noncrystalline Fe and Al in the soil. Recently, Guo and Yost (1999) showed that P extracted with acid ammonium oxalate is a good predictor of the available P pool in the highly weathered soils. We compared the usefulness of this method as an indicator of P availability in soil compared with other methods of P availability such as resin and bicarbonate extraction of Hedley fractionation scheme, iron-impregnated paper strips, and the traditional Bray-II extraction method.

Materials and Methods:

We took advantage of Residual P experiment conducted at Carimagua to compare different methods. The residual effect of a soluble P fertilizer (triple super phosphate) was evaluated in a field experiment carried out at CORPOICA-CIAT research station at Carimagua. The soil is a well-drained Oxisol (tropeptic haplustox, isohyperthermic) with pH of 4.8. The study was carried out in a maize (first semester)-soybean (second semester) rotational crop system established in 1993. Treatments of P application and P rates were: residual P treatment with initial P application rates of 80, 120, and 200 kg P ha^{-1} (one time initial applications at the establishment of the field experiment); and annual P treatment with applications of 0, 20, 30, and 50 kg P ha $^{-1}$ resulting in a total of 7 treatments. The system was evaluated for five years (1993 - 1997), with no P fertilizer application in 1997.

Soil samples (0-10 cm depth) from 1996 sampling were selected to test different methods of P extraction to determine available soil P pool and its relationship to grain yield of maize and soybean. We selected 4 treatments of P application: 0P and 20 kg P ha^{-1} (annual application) and 120 and 200 kg P ha^{-1} (one time initial applications at the establishment of the field experiment). Each treatment had samples from 4 replications.

To quantify the available soil P pool, soils were extracted using:

1) Bray-II (0.1 *M* HCl and 0.03 *M* NH_4F) (Bray and Kurtz, 1945);
2) FeO impregnated filter papers (Menon et al., 1990);

3) Resin strips: anion exchange membranes cut into strips, converted to bicarbonate form (Tiessen and Moir, 1993);
4) HCO_3 (0.5 M) (Hedley et al., 1982); and
5) Acid ammonium oxalate extraction (Guo and Yost, 1999).

Results and Discussion:
Results from the comparison of different methods to quantify the available soil phosphorus pool from either annual (20 kg P/ha) or residual P (120 or 200 kg P/ha) fertilizer applications are shown in Figure 29. The amount of available soil P determined using the acid ammonium oxalate method was significantly greater than that of the other 4 methods of P extraction. The differences among the methods of Bray-II, FeO impregnated filter paper and resin strips were not significant for each level of P application except at 200 kg P/ha. The values of Bray-II and resin-P were identical for each level of P application. When the values of resin-P were combined with the values of bicarbonate P extraction of Hedley sequential fractionation scheme, these combined values were closer to the values of acid ammonium oxalate extraction particularly at higher levels of P application. For annual application rate of 20 kg P/ha, the method of bicarbonate P extraction or the combined values of resin + bicarbonate extraction were more effective in detecting the available soil P level than the acid ammonium oxalate extraction

Results on the relationship between available soil P and grain yield of maize and soybean are shown in Figure 30. For testing these relationships, we selected 3 residual P treatments (0, 120 and 200 kg P/ha). The relationship of available soil P with grain yield was better with the method of Pi-Oxalate than the other methods, particularly for soybean. But resin + bicarbonate P extracted through sequential fractionation of Hedley also showed good relationship with grain yield of both crops.

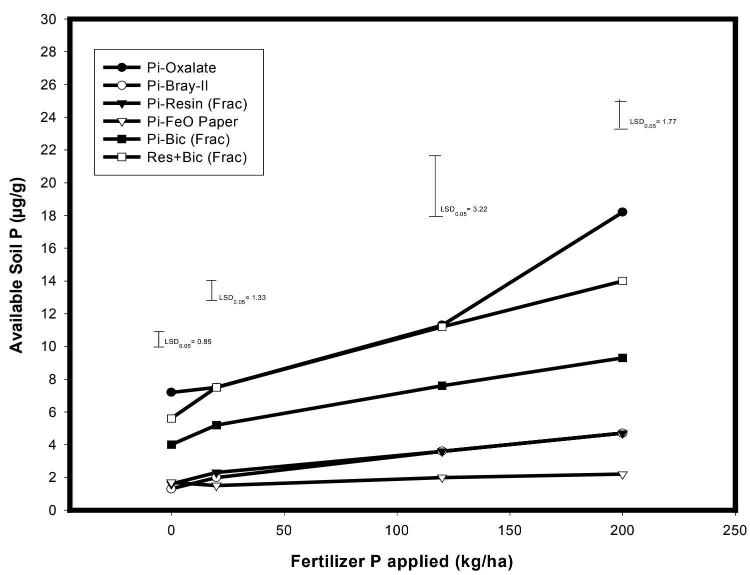

Figure 29. Comparison of acid ammonium oxalate extractable P method with other methods of P extraction to quantify the available soil phosphorus as influenced by fertilizer P application to an oxisol at Carimagua.

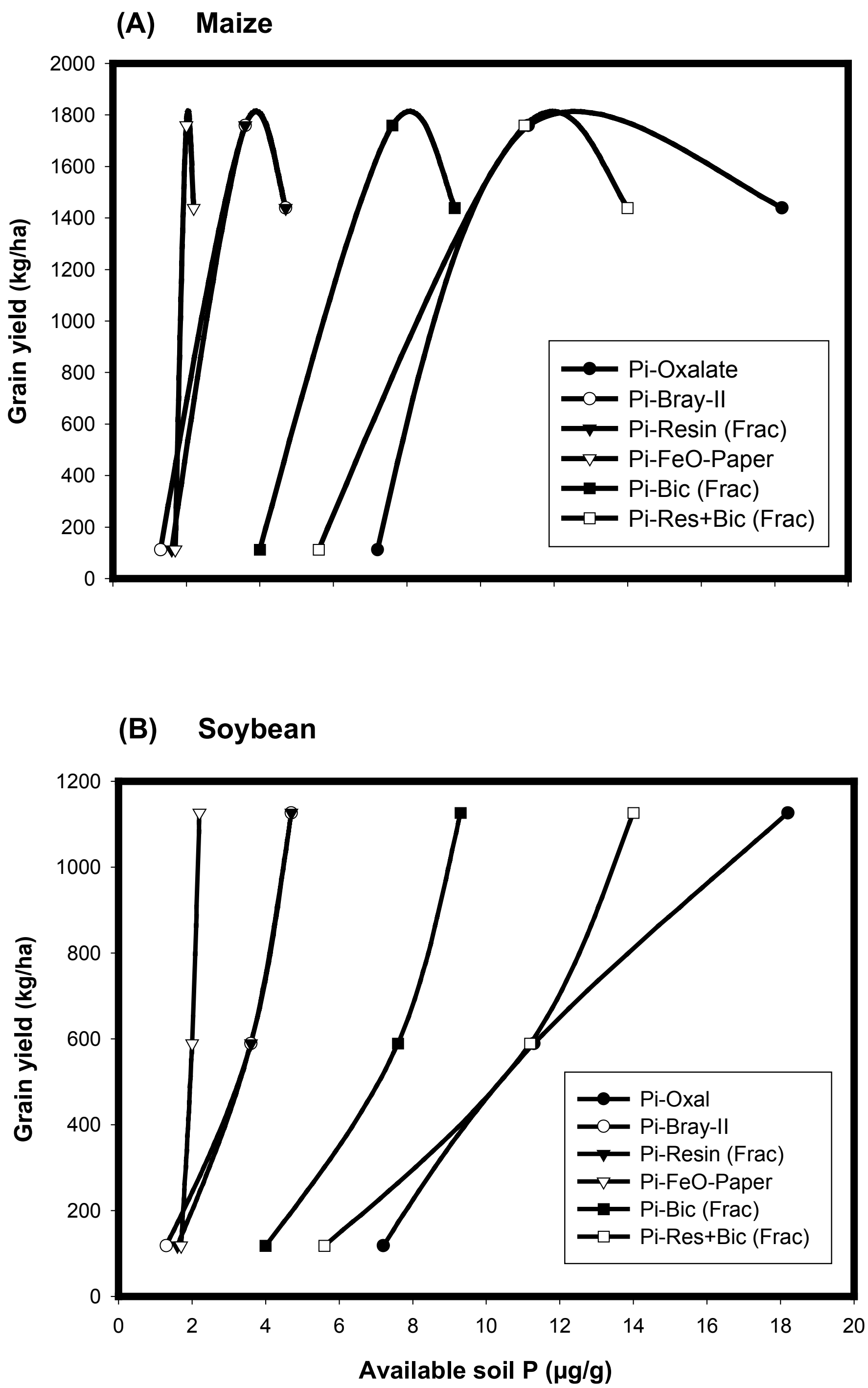

Figure 30. Relationship between available soil P and grain yield of maize (A) and soybean (B). Available soil P was determined with different methods using the residual P treatments of 0, 120 and 200 kg P/ha.

From these results it appears that either oxalate P extraction or the combined values of resin-P + bicarbonate P from the Hedley sequential fractionation scheme may be more suitable for the determination of available P in oxisols when strategic applications of lower levels of P were used. Further research work is needed to test the usefulness of -resin + bicarbonate sequential extraction method of Hedley compared with oxalate method to estimate available soil P and its relationship with grain yield in oxisols.

Impact:
This comparative study of P extraction methods indicated that use of either oxalate-P or resin-P + bicarbonate-P pools of Hedley sequential fractionation scheme are better suited to determine soil P availability in oxisols that receive strategic applications of lower amounts of fertilizer P.

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3.1.2 Adjustment of methods for the simultaneous evaluation of tropical legumes for animal feed and soil improvement

Highlights:
- Showed that differences in plant quality attributes could be more important than sample preparation in determining the extent and rate of decomposition of plant material in the soil and rumen.

Purpose:
To assess the effect of drying plant material on aerobic and anaerobic decomposition of legumes of contrasting quality

Rationale:
It is recognized that legume species are useful to enhance existing feed resources and to contribute to soil fertility in mixed livestock-cropping systems through their use in associated grass-legume pastures, as green manure or as mulch through prunings.

In mixed crop-livestock production systems legume quality is a key factor for obtaining maximum benefits in terms of rate and extent of N release in the rumen or soil. Consequently, Animal Nutritions and Soil Scientists have been interested in defining plant quality parameters that are correlated with release of nutrients from topical legumes. However, research in quality of legumes as it relates to ruminants or soil has been carried out in an independent manner and consequently there has been very little information sharing on methodological aspects.

Microbial populations mainly mediate the decomposition of plant material in the soil with lesser effects from soil macrofauna. Decomposition is often studied using the litterbag technique whereby plant material is placed in or on the soil in series of nylon litterbags. Decomposition is determined by sampling the bags over time of usually several weeks or months and relating the results (DM disappearance and N release) to initial compositional factors of the plant material. This method is resource -and time- consuming but provides valuable data for comparing plant species in terms of their relative decomposition and nutrient release patterns.

Ruminants also decompose plant material through microbes that degrade plant protein and cell wall constituents to ammonia, amino acids and energy for the host animal. To assess the extent and rate of nutrient release from plant material used as a feed resource, samples are incubated with rumen microbes using in vitro systems or alternatively using in situ techniques, which follow the same principle of the soil nylon litterbag method.

It is recognized that soil and rumen processes involved in plant degradation have fundamental differences namely an anaerobic aqueous environment in the rumen, higher number of microbes and much faster degradation rates in the rumen compared with soil. Despite these differences, the extent and rate of nutrient release from plants in the two processes is greatly affected by compositional factors of the plant (i.e. N level, lignin, condensed tannins).

Thus we tested the hypothesis that similar plant chemical entities control decomposition and the release on nutrients in the rumen and soil and that in vitro values on rates and extents of digestion by rumen microbes can be used for predicting decomposition values of legume plant material in the soil.

To test these hypotheses we setup a research program, which involves three phases:

a) Laboratory studies to determine rates and extent of aerobic and anaerobic degradation of plant material from legumes with contrasting quality subject to different drying treatments and using different methods.
b) Laboratory studies to determine relationships between plant chemical entities and aerobic and anaerobic decomposition and release of nutrients in a range of legumes of contrasting quality.
c) Field studies using selected legumes as green manures and indicator crops to validate predictions of equations of nutrient release and in vitro anaerobic and aerobic results.

We hope that through this research we can produce the following outputs:

a) Know applicability of *in vitro* methods used to assess feed value of forages to define potential decomposition and release of nutrients from legumes used as feed resource or to improve soil fertility.
b) Known chemical entities in plant material that controls the extent and rates of decomposition of tropical legumes in the rumen and soil.
c) Guidelines for quick and reliable assessment of the value of tropical legumes as feed resources and for soil improvement.

In this report we summarize results from the first series of laboratory studies in which measured anaerobic and aerobic decomposition of plant material from shrub legumes with contrasting quality and subject to different drying treatments.

Materials and Methods:
The following woody tropical legumes were selected for the initial studies: a) *Indigofera constricta* (low tannin content), b) *Cratylia argentea* (medium tannin content) and c) *Calliandra* sp (high tannin content).

Plant material from the three legumes growing in a hillside site (Pescador, Cauca) was harvested after 6 weeks of regrowth and cuttings (leaf + fine stem) were subjected to the following drying treatments prior to aerobic and anaerobic incubation: fresh, frozen, freeze-dried, oven-dried (60^oC) and air-dried.

All samples were subjected to the following chemical analysis: N, C, P, fiber (NDF and ADF), lignin, soluble and bound condensed tannins and ash following standard protocols.

For measuring anaerobic degradation of DM we used two procedures:

a) **Tilley and Terry *In Vitro* method**, which comprises an incubation of the samples with rumen microorganisms followed by pepsin extraction; and
b) ***In Vitro* Gas Production**, which involves the incubation of samples with rumen microbes and measurement of gas produced at regular intervals using a transducer.

For measuring aerobic decomposition and nutrient release two procedures were used:

a) **Litterbag-Technique:** A greenhouse decomposition trial was carried out to observe decomposition and disappearance-rate of the legume prunings. Litterbags (10 cm x 10 cm, mesh size 1 mm) were filled with 5 g dry matter and placed on the soil surface. Soil from the upper layer obtained in Pescador was air-dried and filled in pots of 17 cm diameter. Pots were arranged in a randomized block design with 5 replicates. Moisture content of the soil was maintained at 60 % of water holding capacity. Sampling of litterbags was done after 1, 2, 4, 8 and 20 weeks. Bags were oven-dried (40^oC) to constant weight with the plant material inside. Later plant material was manually cleaned from soil particles and weeds to determine dry weight and nutrient concentrations at different sample times.
b) **Leaching Tube Assay:** An aerobic leaching tube incubation method (see Picture 12) was used to measure N-release rates from legume pruning. Glass tubes (5 cm diameter and 20 cm length) with a funnel bottom were filled (from the bottom to the top) with a fine layer of glass fiber wool, 10g of acid-washed sand, 90 g of soil/sand mixture (1:1), and 200 mg of the different legume samples. Tubes were arranged in a randomized block design with 5 replicates and kept in a dark room at 26^oC +/- 1^oC. Leaching will be performed 8 times (1, 2, 4, 6, 8, 12, 16 and 20 weeks) with 100 ml of leaching solution (1mM $CaCl_2$, 1mM $MgSO_4$ and 1mM $KHPO_4$). Leachates will be analyzed for NO_3^-, NH_4^+ and condensed tannin content. Results of this experiment will show amount and period of N-release of the different legumes during degradation.

Picture 12. Leaching Tube Setup.

Results on gas production and DM decomposition over time were fitted to appropriate regression models to estimate rates, which were then subject to an analysis of variance with drying treatment and legume species as sources of variation.

Results and Discussion

The effect of drying method on chemical composition of the three legumes used in the study is shown in Table 42. As expected, there were large differences among legumes in cell wall content, lignin and N, which could results in different decomposition rates when exposed to rumen and soil microorganism.

The legume with the highest quality was *Indigofera constricta* (no condensed tannins) given its lower fiber and lignin concentration and higher N level when compared to the other two species. In the case of *Cratylia argentea* with low levels of condensed tannins, the main factor affecting its quality would seem to be the high and lignified cell wall fraction. In contrast, degradation of *Calliandra sp* could be more related to its high tannin content than to fiber and lignin.

Also as expected, drying treatment had a significant effect on the chemical composition of the three legumes included in the test. Results shown in Table 42 indicate that in all legume species, oven drying resulted in more fiber and lignin than freeze-drying or air-drying possibly as a result of artifacts formed by heat damage (Maillard reaction). However, this effect did not result in consistent reduction in the soil or rumen of DM degradation of the legumes under test as we had expected based on results in the literature.

The extent of DM decomposition of the three legumes by rumen microbes using two methods was highly correlated ($r = 98$; $P<0.01$) as has been shown in other studies. We also found a high correlation ($r = 0.87$; $P<0.0001$) between anaerobic in vitro DM loss and aerobic decomposition of DM in the soil, which had been shown in previous studies carried out in CIAT.

One important finding was that in vitro DM degradation by rumen microbes was more affected by legume specie than by drying method, regardless of the *in vitro* method used. The extent of degradation of *I. constricta* was 1.5 times greater than *C. argentea* and almost 3 times greater than *Calliandra* sp, which is a reflection of the different chemical composition of the plant material used in the experiments.

Another parameter measured in the *in vitro* fermentation and litterbag trials was the rate of degradation of the three legumes subject to different drying treatments. Results indicated a positive correlation ($r = 0.49$; $P<0.05$) between anaerobic rate of *in vitro* gas production and aerobic rate of DM disappearance using the litterbag technique.

Results also showed that rates of aerobic and anaerobic rates of degradation were significantly influenced by legume species as shown in Table 43. However, the effect of legume species on rates of degradation was greater when samples were incubated under aerobic than under anaerobic conditions. The rate of DM disappearance of *I. constricta* under aerobic conditions was 4 times greater than *C. argentea* and 7 times greater than with *Calliandra* sp. However, under anaerobic conditions the rate of gas production of *I. constricta* when averaged across drying treatments was only1.4 times greater than with *C. argentea* and 3.5 times greater than with *Calliandra* sp.

One of the objectives of this work is to establish functional relationships between plant chemical components and decomposition and release of nutrients from legumes with contrasting quality in an anaerobic rumen system and in an aerobic soil system. Initial results indicate that cell wall content (ADF) was poorly correlated to DM loss in the anaerobic in rumen *in vitro* system and in the aerobic soil litterbag system, but that negative and significant correlations were observed with ADF (cellulose + lignin) and lignin content (Table 44). By correcting the lignin fraction with condensed tannins and with N the correlations with observed DM decomposition under aerobic and anaerobic conditions significantly improved.

Table 42. Chemical composition of three tropical legumes subject to different drying treatments prior to aerobic and anaerobic incubation

Treatment	NDF (%)	Lignin (%)	N (%)
*Indigofera constricta**			
Freeze-dried	27	5.0	4.6
Oven-Dried (60 °C)	**43**	**5.4**	5.0
Air-dried	30	4.5	5.3
*Cratylia argentea***			
Freeze–dried	57	12.0	3.7
Oven-Dried (60 °C)	**77**	**13.4**	3.8
Air-dried	67	12.6	3.9
*Calliandra sp.****			
Freeze-dried	36	10.3	2.0
Oven-dried (60 °C)	**43**	**13.3**	2.7
Air-dried	35	8.5	2.3

*No tannins
**Low tannins (1- 2 %)
***High tannins (17 to 22 %)

Table 43. Rates of anaerobic (gas production with rumen microbes) and aerobic (DM disappearance in litter bags) rates of degradation of three legumes (Data presented are means across drying treatments)

Legume Species	Anaerobic Conditions- Rumen Microorganisms Rate of in vitro gas production (% / h)	Aerobic Conditions- Soil Microorganisms Rate of DM disappearance (% /d)
Indigofera constricta	8.57 a	1.35 a
Cratylia argentea	6.16 b	0.33 b
Calliandra sp	2.51 c	0.19 c

In general, these results confirm that decomposition of legume plant material in the soil using the litterbag technique is highly correlated with DM disappearance using *in vitro* anaerobic methods. The advantage of this finding is in terms of time and cost savings. While with the litterbag it takes 20 weeks to determine the extent and rate of decomposition of plant material in the soil with the *in vitro* anaerobic system it only takes 48 h to determine extent and rate of degradations of DM from plant material.

Finally, our results suggest that differences in plant quality attributes could be more important than sample preparation in determining the extent and rate of decomposition of plant material in the soil and rumen. Initial results indicate that decomposition of legumes in the soil and rumen is not a function of total cell wall in the plant but rather it is a function of indigestible fractions of the cell wall such as lignin alone or corrected for presence of condensed tannins.

Table 44. Correlation coefficient r-values between different plant chemical components and dry matter (DM) loss in an anaerobic *in vitro* gas production system and an aerobic soil litterbag system

Plant Chemical Components	Anaerobic Conditions- Rumen Microorganisms DM loss (%) r	Aerobic Conditions- Soil Microorganisms DM loss (%) r
NDF	- 0.13 (NS)	- 0.28 (NS)
ADF	- 0.64 (P< 0. 0045)	- 0.66 (P < 0.0014)
Lignin	- 0.74 (P< 0.0014)	- 0.78 (P < 0.0002)
Lignin + Total Condensed Tannins	- 0.95 (P < 0.0001)	- 0.91 (P < 0.0001)
Lignin: N	- 0.98 (P < 0.0001)	- 0.96 (P < 0.0001)

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Activity 3.2 Develop and test a soil quality monitoring system (including indigenous knowledge) for use by farmers and extensionists in hillsides and savannas

3.2.1 Integration of local soil knowledge for improved soil management strategies

Highlight:
- Developed a methodological guide through a participatory approach, to identify and classify local indicators of soil quality related to to permanent and modifiable soil properties. This guide is being used in Latin America and the Caribbean (Colombia, Honduras, Nicaragua, Peru, Venezuela, Dominican Republic) and Africa (Uganda, Tanzania).

Purpose:
To construct the local knowledge platform needed to develop local soil quality monitoring systems.

Rationale:
Current estimates of degradation of the soil resource indicate that we cannot afford to adopt a grow-now and-clean-up-later approach to agriculture. Farmers need early warning signals and monitoring tools to help them assess the status of their soils, since by the time degradation is visible, it is either too late or too expensive to reverse it. Furthermore, the costs of preventing degradation are often several times less than costs of remedial actions. Technical solutions to soil degradation abound but are often left on the scientists's shelves, because they are developed without the participation of the land user or do not build on local knowledge of soil management. A common language is required to link local and technical knowledge so that acceptable, cost-effective solutions to soil degradation can be developed.

There is increasing recognition that local soil knowledge can offer many insights into the sustainable management of tropical soils. A participatory approach in the form of a methodological guide has been developed to empower local communities to better manage their soil resource through better decission making and local monitoring of their environment. It is also designed to steer soil management towards developing practical solutions to identified soil constrains, as well as, to monitor the impact of management strategies implemented to address such constraints. The methodological approach presented here constitutes one tool to capture local demands and perceptions of soil constraints as an essential guide to relevant research and development activities. A considerable component of this approach involves the improvement of the communication between the technical officers and farmers and *vice versa* by jointly constructing an effective communication channel. The participatory process used is shown to have considerable potential in facilitating farmer consensus about which soil related constraints should be tackled first. Consensus building is presented as an important step prior to collective action by farming communities resulting in the adoption of improved soil management strategies at the landscape scale.

A considerable proportion of soil degradation induced by human-related activities is a result of deforestation, overgrazing and improper agricultural practices. Eighty five percent (85%) of agricultural land is estimated to have some dregree of degradation. The mounting evidence of land degradation induced by agriculture is resulting in a gradual shift from a high input agriculture paradigm, based on overcoming soil constraints to fit plant requirements by amending soils with fertilizers, lime, biocides and tillage, to a paradigm with more reliance on biological processes. This paradigm invokes a more ecological approach based on the adaptation of germplasm to adverse conditions, the enhancement of biological activity of the soil and the optimization of nutrient cycling to minimize external inputs and maximize the efficiency of their use. This new paradigm focuses on the need to improve agricultural production in more benign ways compared with traditional agricultural improvement that is based on high inputs with subsequent detrimental environmental impacts that result in soil degradation. Nevertheless, while this paradigm shift is a good sign its beneficial impact, in terms of improved soil management options for healthier landscapes, will be limited if there is little adoption by local land managers. Increased application of indigenous knowledge to rural research and development can be attributed to the need to improve the targeting of research to address client needs and thus increase adoption of technological recommendations derived from research. It is thus argued that research efforts should further explore a suitable balance between scientific precision and local relevance resulting in an improved knowledge base as indicated in Activity 1.3.1.

Materials and Methods:
A participatory approach for integration of local and technical knowledge systems: A common language is required to link local and technical knowledge about soils and their management so that acceptable, cost-effective strategies for improved soil management can be developed. For this purpose a methodological guide has been developed and used in Latin America and the Caribbean (Trejo et al., 1999) and Africa (Barrios et al., 2001) in order to help stakeholders identify and classify local indicators of soil quality (SQI) related to permanent and modifiable soil properties as this is the first step in the development of local soil quality monitoring systems (Figure 31).

Selecting a suitable set of SQI, and developing its use as a monitoring system (Soil Quality Monitoring System, SQMS), can be captured in the following Figure:

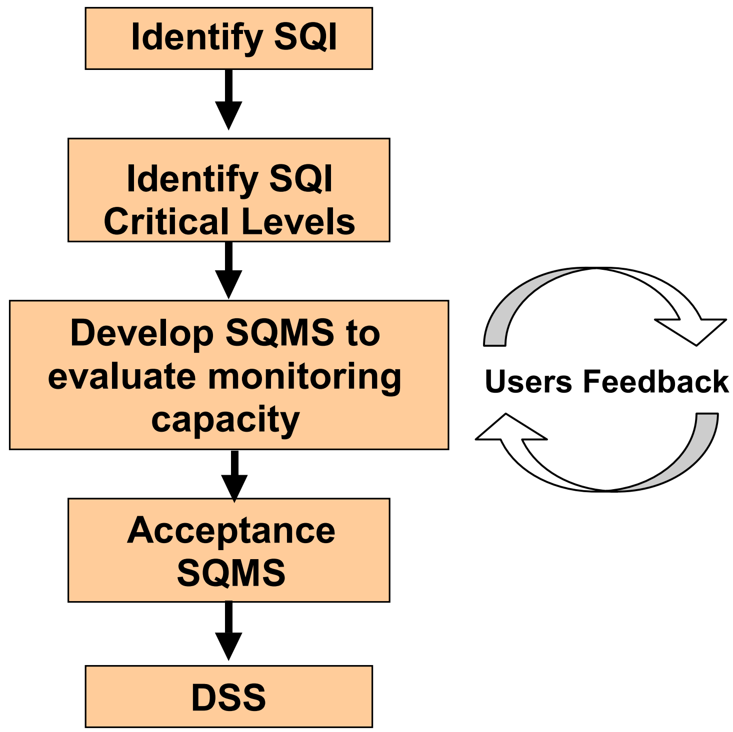

Figure 31. Process leading to the development of Soil Quality Monitoring Systems (SQMS) as Decision Support Systems (DSS).

Results and Discussion:
Suitable SQI are identified from the local and technical knowledge base and critical levels defined. This phase is followed by the definition of guidelines to establish a Soil Quality Monitoring System (SQMS) along with interpretation information as well as reaching an agreement about the suitable SQI for the relevant conditions. User feedback is very important at this stage as it will provide the grounds for acceptance of the SQMS for soil quality diagnosis and monitoring. Once the SQMS is fully accepted by users it becomes part of the Decision Support System for Natural Resource Management

This methodological guide is mainly focused on the first phase of this process; i.e.: identifying soil quality indicators that can be used by farmers, extension officers, NGO's, technicians, researchers and educators. The SQI will help in identifying the main soil biophysical limitations of the agricultural system under study. The most sensitive and robust SQIs selected for the soil constraints identified can then be incorporated into a Soil Quality Monitoring System (SQMS), and should include basic parameters such as bulk density, pH, effective rooting depth, water content, soil temperature, total C and electrical conductivity. Since our objective is to develop a SQMS for the land users, local indicators of soil quality must be included in the monitoring system. The mix of native and scientific parameters varies according to the monitoring objectives; e.g.: if they are farmers, extension agents or policy makers. It is likely that integrative SQI might be more useful to land users, than a measurement, for example, soil available P, since many indicators used by the farmers are also of the integrative type; for instance, soil color, soil structure, crop yield, presence of specific weed species. Attention should be paid to the inclusion of indicators that can be used while progressively increasing the scale at which results are applied (e.g. from plot to field and farm level, up to watershed, region and nation level). Some examples of such indicators might be crop yield and yield trends, land cover, land use intensity and nutrient balances. More recently, the use of resource and nutrient flows at farm scale has been proposed to assess land use sustainability and local variation usually missed in studies at higher levels of aggregation (i.e. region, country).

The methodological approach proposed by Trejo et al. (1999) and Barrios et al. (2001) rests on the belief that in order for sustainable management of the soil resource to take place, it has to be a result of improved capacities of the local communities to better understand agroecosystem functioning. Improved capacities by technical officers (extension agents, NGO's, researchers) to understand the importance of local knowledge is also part of the methodology. Therefore, after identifying if there is poor or a lack of adequate communication between the technical officers and the local farm community as a major constraint to capacity building, the methodology proposed deals with ways of jointly generating a common knowledge that is well understood by both interest groups. The structure of the guide in Figure 32 shows the different sections of the methodological guide for Africa.

This methodological guide aims to empower local communities to better manage their soil resource through better decission making and local monitoring of their environment. It is also designed to steer management towards solutions to the soil constrains identified as well as to monitor the impact of management strategies implemented to address such constraints.

This methodological guide is made up of six sections: Section 1 provides a general introduction about the management of the soil resource in the African context and the ISQ. Section 2 presents a technical conception of the soil through a Simplified Model of Soil Formation (SMSF) based on Jenny's seminal work in order to bring participants to a common starting point. It also introduces the technical indicators of soil quality (TISQ) with the participation of professionals from National Research and Extension Organizations (NARES), NGO's, universities and International Agricultural Research Centers. Section 3 deals with participatory techniques that help gather, organize and classify local indicators of soil quality (LISQ) through consensus building and this is conducted with local farming communities. The process to elicit information about local indicators of soil quality starts with a brainstorming session guided by trainers where local farmers explain, in their own words, how they define and classify the quality of their soils. Once local indicators have been collected a ranking session is initiated where the original group of farmers is split into smaller groups of 3 or 4 in order to carry out several ranking exercises for the same information and thus obtain a more representative mean value. All results obtained from each group conducting the ranking exercise are put together in a ranking matrix where rows represent all local indicators identified during brainstorming and the columns represent the ranking assigned by different small groups of farmers.

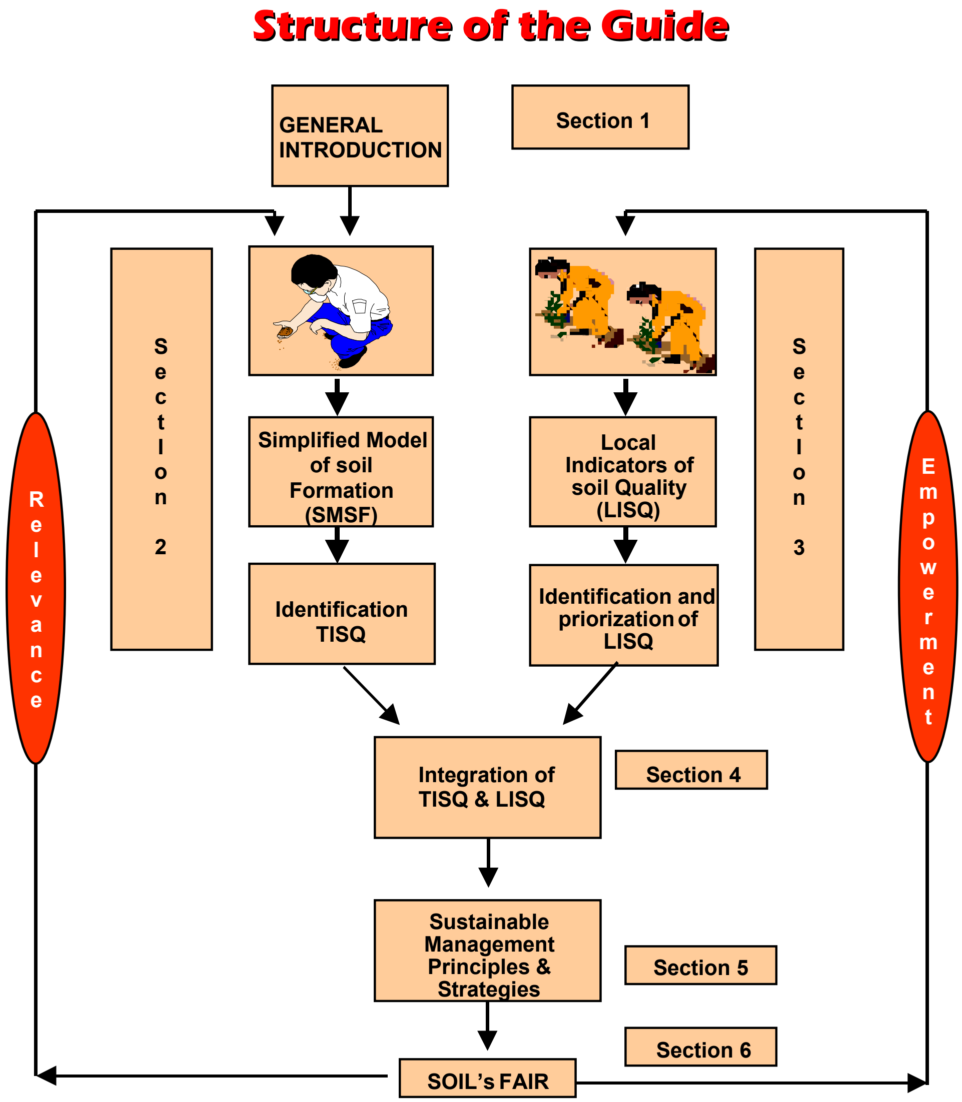

Figure 32. Structure of the methodological guide for Africa.

Section 4 provides a methodology to construct an effective channel of communication by finding correspondence between TISQ and LISQ that permit a better Extension/NGO officier – farmer communication. This is carried out in a plennary session exercise of integration where the most important local indicators of soil quality are analyzed in the context of technical knowledge and are classified into indicators of permanent or modifiable soil properties (Table 45). The classification of local indicators into permanent and modifiable factors provides a useful division that helps to focus on those where improved management could have the greatest impact. This strategy is particularly sound when there is considerable need to produce tangible results in a relatively short time in order to maintain farmer interest as well as to develop the credibility and trust needed for wider adoption of alternative soil management practices.

Table 45. Integration of LISQ identified and ranked by farmers of Jalapa village, Yoro, Honduras with TISQ and their association with permanent or modifiable soil properties.

Ranking[a/]	Knowledge integration		Property	
	Local	Technical	P[b/]	M[c/]
1	Thick soil layer/thin soil layer	Effective soil depth	X	
2	'Opulento', no need of chemical fertilizer/ needs fertilization	Soil fertility		X
3	Presence of earthworms/ lack of earthworms	Biological activity		X
4	Soils with gentle slopes, uniform/ soils with high slopes	Slope	X	
5	Soil macroaggregates can be broken into pieces, lose soil/ Macroaggregates can not be broken, tied soil	Structure	X	
6	Soil keeps water for longer time/ soil does not keep water	Texture / water holding capacity	X	
7	No burnings have occurred in the last 5 years/ Lands have been burned in the last 5 years	Soil burning		X
8	Black / various soil colors	Color	X	
9	Fast water absorption/ slow water absorption	Texture / infiltration	X	
10	Loamy soils, little clay/ 'Barrialosa' or "muddy", sandy	Texture	X	
11	'Zaléa', 'Chichiguaste'/ 'Chichiguaste' does not grow, weeds do not develop, 'zacate de gallina'	Indicator plants		X
12	Easy tillage/ difficult tillage, 'Tronconosa'	Physical barriers	X	
13	Greater yields/ Lower yields, more work to produce	Productivity		X
14	No stones present / 'Balastrosa', stony, gravely	Stoniness	X	
15	Soil does not flood, no 'aguachina'/ 'aguachina', soil sweats	Drainage	X	
16	Non washed soils/ washed soils	Erosion	X	

a/ Degree of importance given by farmers
b/ P: permanent property
c/ M: modifiable property

Although some local indicators can be rather general like fertility, slope, productivity and age under fallow, other local indicators are more specific. For instance, plant species growing in fallows, soil depth, color, water holding capacity and predominant soil particle sizes provide indicators that can be easily integrated with technical indicators of soil quality.

Results to date indicate that biological indicators like native flora (see activity 1.3.1) and soil macrofauna (see activity 3.2.2) are important components of local indicators of soil quality. This is not surprising as biological indicators have the potential to capture subtle changes in soil quality because of their integrative nature. They simultaneously reflect changes in the physical, chemical and biological characteristics of the soil. There is considerable scope, therefore, to further explore the use of local knowledge about biological indicators of soil quality and as a tool guiding soil management decisions.

Section 5 is concerned with management principles behind potential strategies to address constraints modifiable in the short (< 2 yrs), medium (2-6 yrs) and long (> 6 yrs) term. Modifiable constraints are those that can be overcome through management. Examples include low nutrient and water availability, low and high pH, soil compaction and low soil organic matter content. The discrimination between short, medium and long term is necessary to enable ranking of management strategies, which is mainly dictated by resource endowment.

Section 6 is devoted to the Soils Fair which is designed to help farmers develop skills to characterize relevant physical, chemical and biological properties of their soils through simple methods that can then be related to their local knowledge about soil management. Here farmers and scientists communicate through a commonly developed language and simple demonstrations on how to measure soil quality *in situ* to solve local soil management and land degradation problems.

The result of this two-way exchange process is that it has a positive impact on the technical knowledge by nurturing it with local perceptions and demands. The number of improved soil management experiences will likely increase because of the solid basis provided by local relevance. Positive impacts are also envisioned on the local knowledge base as it provides with a way for this tacit knowledge to be widely understood, assessed and utilized. Besides, local communities will be empowered by the joint ownership of the technical-local soil knowledge base constructed during this process.

The two-way improvement of communication channels will likely improve the communication of farmer's perceptions to extension agents and researchers as well as make recommendations by extension agents and NGOs better understood by the farmer community. Better communication opens opportunities for established and/or emerging local organizations to use this methodological approach for consensus building that precede collective actions resulting in the adoption of improved soil management strategies at the landscape scale.

Action plans: Finally, participants in the training event associated with the guide are encouraged to develop "action plans". These action plans show the institutional commitment made by participants to apply the guide and gained insights in their own work plans and environments. To date more than 23 action plans have been initiated in Latin America and Africa. Follow up of these action plans in the coming years will provide a measure of the impact of this participatory approach in better natural resource management through improved soil management strategies.

Participatory approaches involving group dynamics and consensus building are likely to be key to adoption of improved soil management strategies beyond the farm-plot scale to the landscape scale through the required collective action process. Action plans developed by local actors as a result of consensus building and new insights derived from the training exercise become a vehicle by which profitable and resource conserving land management is locally promoted and widely adopted. Taking advantage of the complementary nature of local and scientific knowledge is highlighted as an overall strategy for sustainable soil management.

Impact:
The approach summarized in this activity provides the tools to conduct a technical-local classification of the soil, based on modifiable and permanent soil properties, which has the flexibility to work in the spatial scale continuum plot/farm/landscape (watershed) while also having the potential to take the stakeholder groups and gender issues dimensions into consideration. This guide then provides a valuable tool to evaluate the impact of the land use change across various spatial scales and social actors.

The development of these methodological guides has been a good example of 'South – South' cooperation where experiences from Latin America were brought and adapted to the African context, and feedback from Africa has helped further improvement of the Latin American guide.

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Trejo M.T., Barrios E., Turcios W. and Barreto H. (1999) Método Participativo para identificar y clasificar Indicadores Locales de Calidad del Suelo a nivel de Microcuenca. Instrumentos Metodológicos para la Toma de Decisiones en el Manejo de los Recursos Naturales. CIAT-CIID-BID-COSUDE.

Contributors:

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3.2.2 Local knowledge about natural resources at watershed scale: the case of land use classification and soil fauna

Highlights:

- Showed that distribution and abundance of soil macrofauna appears to be related to local land calssification units.

Purpose:

To generate information about local knowledge of the soil and land resources in hillside agro-ecosystems.

Rationale:

In 2000, a local land use classification was investigated in the CIAT benchmark site in Pescador, Cauca. The local classification contains eight major categories that are based on physical, chemical and topographical characteristics of the Potrerillo microwatershed. To determine meaning behind this local classification we investigated occurrence of soil fauna and vegetation within these categories. The produced results will directly help to implement the project work on harmonizing scientific rigor and local relevance for improved management of natural resources as described in Output 4 (Complementary and special projects).

Results:

Preliminary findings are capture in Figure 4. It is for example clear that earthworms as a soil quality indicator dominate in the soils considered fertile by local farmers as reported in earlier studies for the Cabuyal watershed. Interesting are findings that illustrate the role of ants in infertile soils, or the role of beetles in soils that have been exhausted by nutrient mining. These and other findings warrant further investigation.

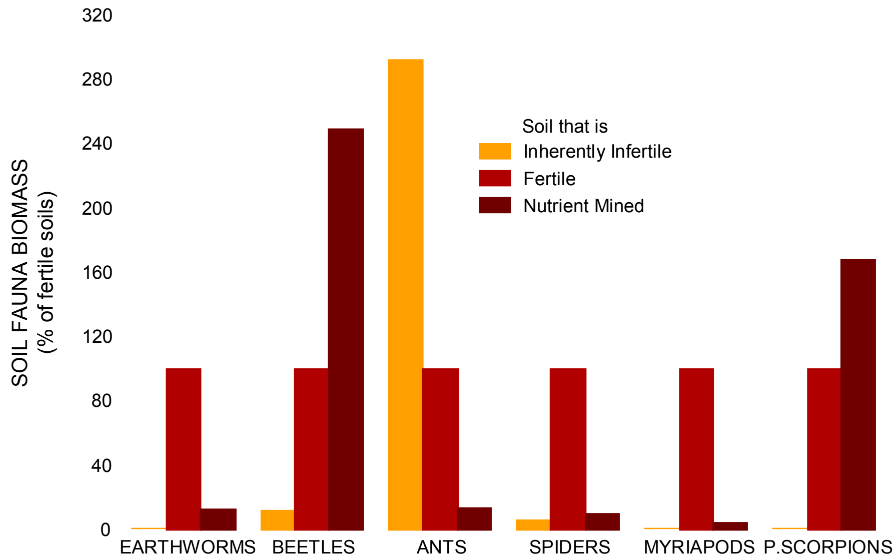

Figure 33. Biomass of functional soil fauna groups including earthworms, beetles, ants, spiders, myriapods and pseudo scorpions determined for three categories of a local land use classification (fertile soils FS, inherently infertile soils IS and soils that have been exhausted by nutrient mining ES). Biomass found in IS and ES was plotted relative to biomass in FS that was set to 100%.

Impact:
Measurable impact will be generated when these results are used to modify and improve land management strategies that explicitly integrate soil fauna.

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Activity 3.3 Compile databases to feed into simulation models and decision support systems

3.3.1 Creating a database for the long-term field experiments carried out in savannas and hillsides agroecosystems

Highlight:
- Created a database for the past and present field experiments in savannas and hillsides agroecosystems to facilitate further analysis and use by PE-2 and other CIAT projects.

Purpose:
To organize and create a database for the long-term field experiments carried out in savannas and hillsides agroecosystems.

Rationale:
Over the past few years, the soils project (PE-2) of CIAT has several field experiments either completed or in progress in both tropical savannas and hillsides agroecosystems. The data collected from these field studies need to be organized systematically. The organized database can facilitate not only further analysis

and interpretation of data by soils project staff but also can be extremely useful to different projects of CIAT.

Results and Discussion

More than 200 files (Lotus, Excel and SAS documents) were used to create the database (Figure 1). They contained data from measurements carried out during the last few years. Most of these data were in different formats. This information was organized and at present stored in the Oracle institutional database of CIAT.

To organize the data, three big blocks were established: one block for hillsides agroecosystem and two blocks (Culticore and Plains (Altillanura)) for savannas agroecosystem. For hillsides agroecosystem, data from 1995 to 2000 were organized systematically. For savannas, organization of data files from Culticore experiment from 1993 to 1999 was completed while the data of Altillanura are still being organized.

A standard format is developed in Excel for adding new data to this database (Figure 2). The criteria for using this format are developed so that data collection system used within the project by research and support staff is uniform across sites and experiments. The process for adding data to the database is very simple. There are three steps: first to create the Excel files for the new samples/observations; second to have the privilege of adding information to the database by pressing the finish button in the Excel format to create the files, then load those files to the database in Oracle and enter the new sites, trials or treatments, and third to have easy access for users to consult the information from the database

The soils project was allocated space in the CIAT documentation center for the publication of documents that can be shared with other units internally within CIAT. There are about 70 files (word, power point, pdf, etc.) as articles, posters and presentations. These can be accessed through CIAT intranet (Figure 1).

In addition to database, information on the CIAT collection of arbuscular-mycorrhizae was organized as a catalog that can be accessed by CIAT staff through intranet.

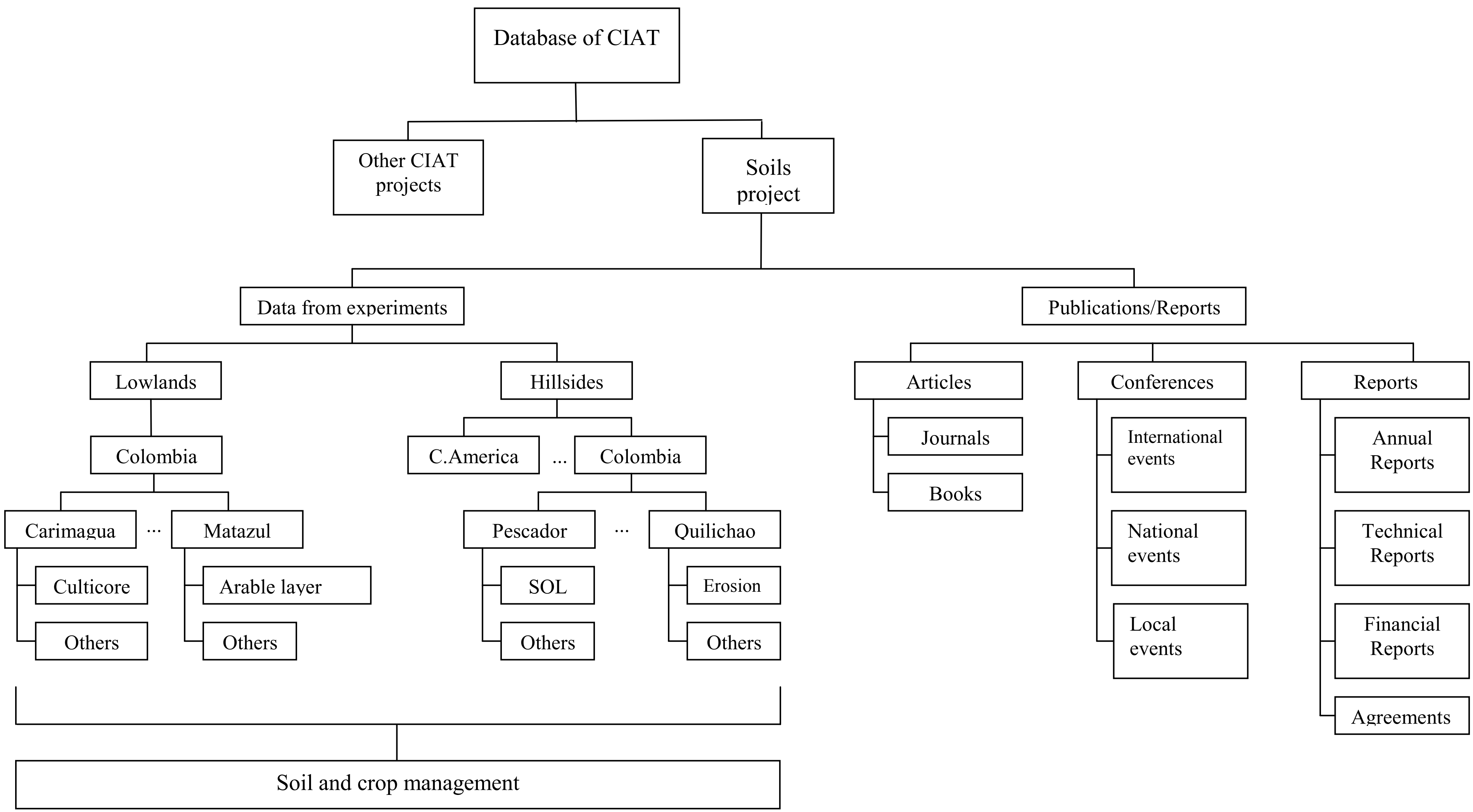

Figure 34. Descriptions of the structure of the database of Soils project (PE-2).

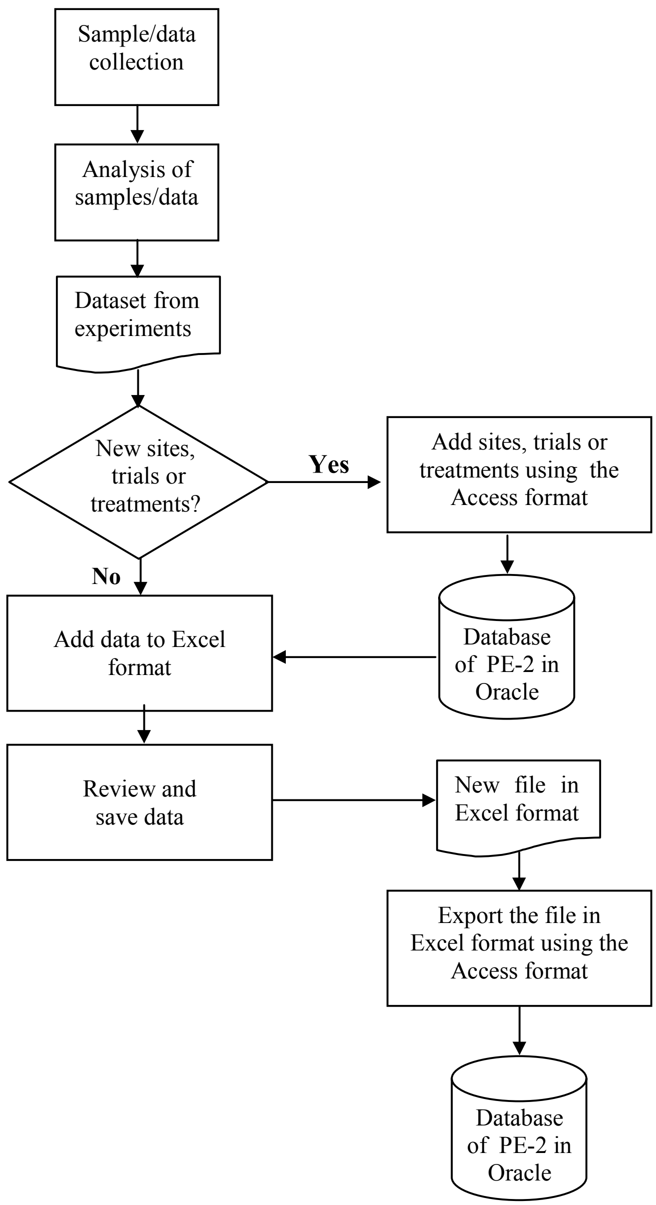

Figure 35. The process of compilation and storage of data for each sample/ observation from Soils project (PE-2).

Impact:
A database was created for the past and present field experiments of savannas and hillsides agroecosystems to facilitate further analysis and use for soils project and other projects of CIAT. This database contains valuable information on soil and crop management strategies for sustainable production in both hillsides and savannas agroecosystems.

Contributors:
C. García, A. Franco, E. Amézquita, I. M. Rao, R. Thomas, E. Barrios, J. Jimenez, L. Chávez, M. Rivera, J. Galvis, J. Ricaurte, J. Cobo, N. Asakawa, I. Corrales, D. Molina and P. Hoyos.

Activity 3.4 Develop decision support tools for improved soil, water and crop management

Progress on this activity will be reported next year.

Activity 3.5 Develop and test a decision support systems for organic materials

Activities conducted in Colombia and currently in Centroamerica will be presented together next year.

Activity 3.6 Develop soil degradation risk assessment maps

3.6.1 Develop a georeferenced soil data bank to generate soil maps and to plan land use in the Easter plains of Colombia

Highlight:
- Developed soil maps for the municipality of Puerto López, Colombia, using a georeferenced soil data bank (GEOSOIL) to facilitate land use-planning and site-specific soil management recommendations .

Purpose:
To develop a GIS based soil mapping tool to support the decision-makers in land use planning and agronomists for improved soil management.

Rationale:
The development of tools and techniques of Geographical Information Systems (GIS) has contributed to different disciplines such as agronomy, geography, digital cartography, and remote sensing. During the last few years, CIAT researchers have focused their activities in GIS to improve land use planning for better management of natural resources and to support decision-makers. The main objective of this work is to link GIS with data on soil properties in order to generate maps of soil quality. These maps are useful to improve land use planning and soil management for improved and sustained agricultural productivity while conserving natural resources.

Materials and Methods:
Field Work. An intensive soil sampling was carried out over an area of 20,000 ha covering the municipality of Puerto López (Altillanura plana). Seventy two field sites were identified for data collection on soil properties. Soil pits were dug for profile descriptions and for sampling at different soil depths (0-5, 5-10, 10-20 y 20-40 cm). In addition to the above soil pits, four representative model profiles were selected for taxonomic verification. The following parameters were considered for measurement and analysis:
Site description (georeference)

Identification of horizons
Descriptions of color (Munssel table)
Texture (organoleptic method)
Texture modifiers (% gravel)
Structure (type, class, degree)
Presence of cutans
Presence of concretions
Consistence (dry, wet)
Soil strength (3 measurements at depth, Torvane)
Resistance to penetration (3 measurements per pit using a penetrographer)
Effective soil depth
Drainage
Soil moisture

Soil Sampling. Nested analysis of variance requires a hierarchical dataset and the hierarchical levels in the data are based on sampling distance. Four levels were chosen corresponding to sampling distances of 5, 50, 1000 and 4000 m. The distances are arbitrary but were chosen on the presumption that a sampling interval of 5 m would encompass almost all of the spatial variation. Variation due to large (e.g. geological) structures would be accounted for in the 4000 m interval. The number of replicates at the first level of 4000 m sampling distance was 8. The remaining levels were subdivided two at a time, resulting in 8 x 2 x 2 x 2 = 64 replicates at the fourth level, equal to the total number at sampling points. To cover more area and to be more precise in the understanding of spatial variability an additional point was taken, thereby increasing the replicates from 64 to 72 points. In each point, a soil pit (50 x 50 x 50 cm) was dug and samples were collected for the determination of the following soil properties at different depths:
Soil water content
Bulk Density
Macroporosity and residual porosity
Texture (Boyucos)
Sand fractions
Hydraulic conductivity
Air permeability
Organic carbon
pH
Elemental analysis (Ca, Mg, K, P, Al, Zn, CEC)

Geostatistical Analysis. The soil data are being analyzed using multivariate analysis with the purpose of determining whether there are correlations among measured variables. This preliminary analysis will permit to identify more sensible soil parameters to change with land use. This geoestatistical analysis is being carried out using the following software: Surfer16 and GIS-Spring to generate maps of isolines for each soil property. So far, we have completed generation of maps of soil pH and resistance to penetration.

Results and Discussion:
Using data collected from field and analysis from laboratory, it was possible to generate maps as shown in Figures 1 and 2. Figure 1 shows a preliminary map of soil pH distribution for the study area of 20000 ha. To construct the map, Surfer-16 software was used. The intensity of color from yellow to red indicates the increase in values of pH. The dark red color indicates the higher values and the yellow color indicates the lower values. The soil pH values in the study area varied from less than 3.9 to more than 4.4. Based on these soil pH values, it is possible to develop site-specific recommendations for lime application to different crop and pasture systems. Therefore, these type of soil maps are extremely useful to plan land use and also to develop site-specific soil management recommendations.

Resistance to penetration is a key soil physical property that affects root penetration and thereby crop or forage adaptation to infertile, Al-toxic acid soils of the Altillanura. Figure 2 shows the spatial variability in resistance to penetration at three soil depths (5, 10 and 20 cm) in the study area. The light color of yellow indicates lower values of resistance to penetration while the dark color of red indicates higher values. There are is a good correlation of values among the three soil depths.

Impact:
Results from this study indicate the importance of integrating GIS tools with soils data to generate soil maps. These soil maps are extremely useful for: (i) planning land use changes; (ii) developing site-specific recommendations for better soil management; and (iii) targeting crop and forage cultivars to specific ecological niches

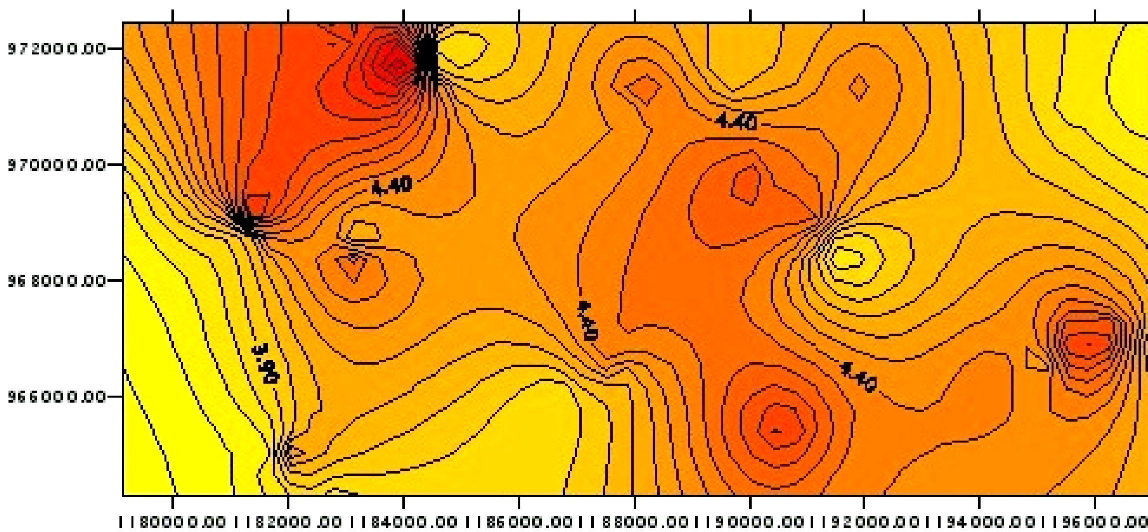

Figure 36**.** A preliminary soil map showing spatial variability of soil pH in the study area of Puerto Lopez. Software Surfer-16 was used to generate the soil map. The intensity of color from yellow to red indicates the increase in values of pH.

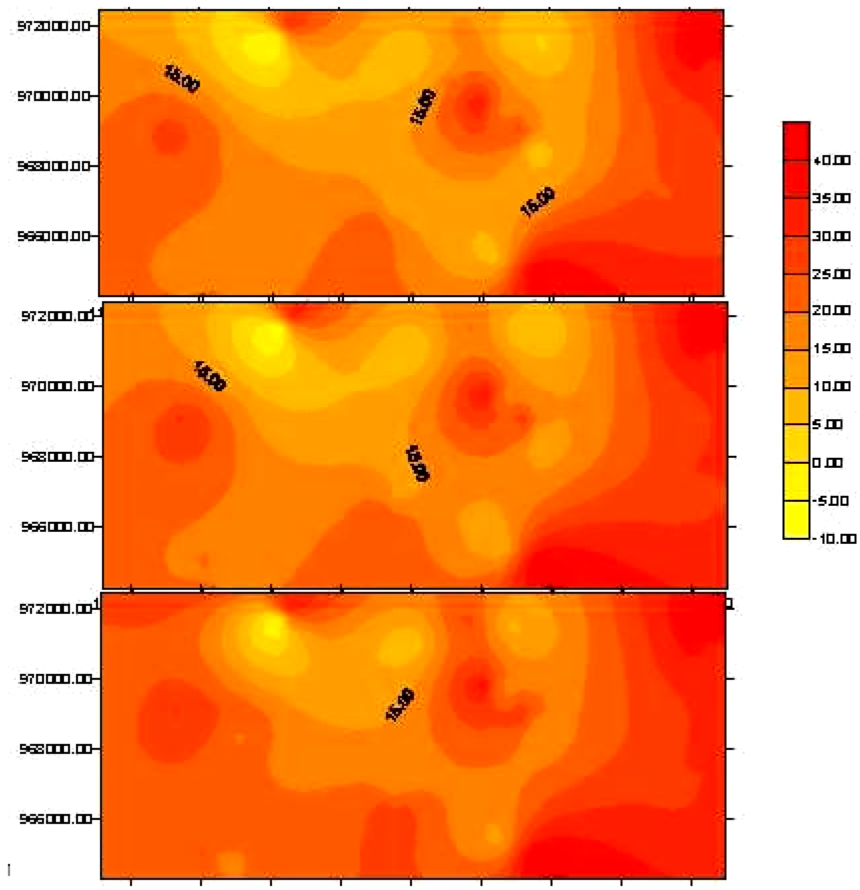

Figure 37**.** A soil map showing spatial variability in resistance to penetration in the study area of Puerto Lopez. Software Surfer-16 was used to generate the soil map. The intensity of color from yellow to red indicates the increase in values of resistance to penetration.

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