Output 1. Soil, water and nutrient management constraints assessed and plant components characterized for improved production and resource conservation

Activity 1.1. Determine and characterize edaphic and climatic constraints

1.1.1 Assessing nutrient constraints for the intensification of agricultural production in hillsides of Central America

Highlight:

- Showed that the supply of both N and P limit corn yields at Central American reference sites

Purpose:

To determine whether N, P and K are limiting maize growth at the SOL sites of Honduras and Nicaragua.
To relate the limitation in N, P and K to topsoil properties.
To identify entry points for soil fertility research in the reference sites of Honduras and Nicaragua.

Rationale:

Hillside farmers are an important source of domestic food supply in many developing countries. Over 60% of the region's maize is grown on hillside plots, and a large proportion of all beans. Crop yields, however, are significantly lower than in lowlands. This reflects a combination of socioeconomic and biophysical constraints. Most of these hills have large predominantly poor and rural populations with limited access to capital and technology. On the other hand, many hillside soils are fragile - shallow, nutrient deficient and prone to soil and water losses. They require careful husbandry and active soil-building efforts to maintain or increase yields.

Increased agricultural productivity and profitability, together with the development or rehabilitation of the "natural capital", of poor hillside communities could contribute significantly to poverty alleviation.

The purpose of this work was to quantify the degree of response of corn to fertilization as an initial step to identify nutrient constraints and develop sound management strategies to improve soil fertility.

Materials and methods:

Study site: The present study was conducted in the SOL sites of Honduras (Luquigue) and Nicaragua (Wibuse). Luquigue is located at 15^{o} 2' N and 87^{o} 15' W and Wibuse at 12^{o} 45' N and 85^{o} 51' W.
Climate and soil characteristics: The average annual precipitation in the area of influence of the SOL-Luquigue is 1572 mm and in the area of influence of Wibuse is 1200 mm. The altitude of the two sites are 720 and 625 m.a.s.l respectively . However, their position in the landscape is different. The Luquigue site is in the lower part of the Tascalapa watershed and Wibuse in the higher part of the Rio Calico watershed. Soils in both sites are slightly acid with moderate contents of SOM and nutrients (Table 1). Soils in the Luquigue site have a loamy clay texture and are derived from sedimentary materials from the Cretaceous. The Wibuse site has a clayey texture soils derived from volcanic ashes from the Tertiary.

Experimental protocol: A limiting nutrient trial was set up in the two sites following the protocol developed by Buresh (1999). It consisted of an arrangement of N, P and K as follows: 1) control; 2) + 100 kg/ha N; 3) +100 kg/ha P; 4) +100 kg/ha N+100 kg/ha P; and 5) +100 kg/ha N+100 kg/ha P + 100 kg/ha K. Treatments were distributed in the field using a Complete Randomized Block Design with four reps. Nitrogen and potassium rates were applied as split applications in the row 20 and 40 days after corn planting. All P was applied at planting.

Table 1. Initial chemical properties found in the 0-15 cm topsoil of the sites selected for the experiment in the SOL in Luquigue, Honduras and Wibuse, Nicaragua.

Nutrient	SOL-Luquigue	SOL- Wibuse
PH	6.4	5.8
SOM (%)	5.0	5.8
N total (%)	0.2	0.3
P (ppm)	9.0	11
K (ppm)	61	12
Ca (ppm)	1960	5140
Mg (ppm)	695	1580
Fe (ppm)	80	23
Mn (ppm)	18	15
Cu (ppm)	1.8	2.2
Zn (ppm)	0.9	0.4
Mg/K	37	8.4

SOM = soil organic matter

Corn variety used in the Luquigue site was HB 104 and NB-6 in the SOL-Wibuse.
Plant parameters evaluated during the experiment were: 1) plant height and nutrient content at flowering time; 2) number and weight of cobs per plant and; 3) grain yield.

Results and Discussion:
There was a marked effect of fertilization on crop development at both sites. Plants were taller with the +N+P or N+P+K treatments as compared to the single applications of N or P (data not shown). Plants receiving only N showed symptoms of chlorosis with young leaves probably related to Mg deficiency.

Grain yields at SOL-Luquigue increased by two fold with either +N+P or +N+P+K application (Figure 1). The single application of P increased by 40% grain yields as compared to the control treatment while the N alone treatment reduced them by the same magnitude. These results shows the clear need for the combined application of N+P in order to improve corn productivity at this site.

Responses to fertilizer application in the SOL- Wibuse site were similar to those found in the Luquigue site. However, differences were not statistically significant due to high spatial variability in the experiment.

In spite of the relatively high contents of total N and moderate availability of P in the soils of the two sites corn responded markedly to N and P fertilizer applications. This result suggests that most of the inorganic fractions have been depleted during the process of land use intensification due to little use of inputs.

During the present year, the work has been expanded to a network of farm fields located at different positions in the watershed in order to confirm fertilizer responses at different altitudes, parent materials and land use history. Results will be reported next year.

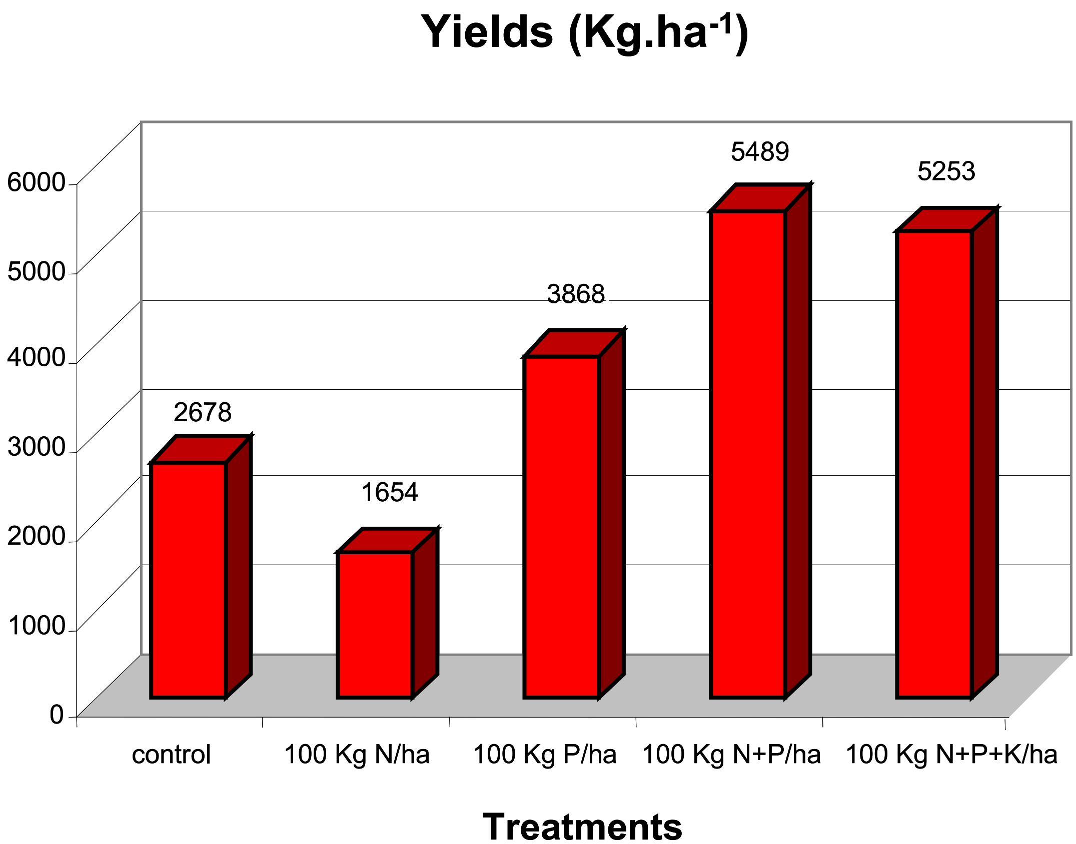

Figure 1. Maize response to N, P and K fertilizer applications at the SOL Luquigue site.

References

Buresh, R. 1999. Productivity evaluation test kit. In: Combined Inorganic-organic Nutrient sources: Experimental Protocols for TSBF-AfNet, SoilFertNet and SWNM. TSBF, Nairobi, Kenia.

Contributors:

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1.1.2 Characterization of the phenomenon of soil crusting and sealing in the Andean Hillsides of Colombia through evaluation of physical and chemical characteristics

Highlights:

- Showed that: (i) excessive application of chicken manure as an organic fertilizer on Andean volcanic ash soils leads to soil crusting and sealing by physical/chemical dispersion mechanisms and the interaction of physical and chemical characteristics; and (ii) improper land use and fertilization practices can markedly reduce cassava root yields.

Purpose:

To characterize the phenomenon of crusting and soil surface sealing on Andean volcanic ash soils, and to develop land use and soil management recommendations for endangered areas.

Rationale:

Land resources throughout the world are being increasingly destroyed. Specifically, an increase in soil destruction is mainly due to soil degradation through water and wind erosion, with additional physical and chemical deterioration. Tropical and subtropical hillside areas and steep slopes are most affected, even more than soils in the temperate zone, because of intensive climate and poor soils. These soils face extreme risk of becoming completely depleted.

The Andes of South America is an area vulnerable to soil erosion. The local political situation coupled with socioeconomic constraints encourages unsustainable land use and fertilizer management. These practices can significantly change soil properties. This change of physical and chemical stability decreases soil fertility and productivity to the point that farming is severely affected. Especially rural farmers who produce their food on steep slopes are most affected by this phenomenon, which results in their loss of income and livelihood.

Soils, partly influenced by volcanic ashes in the Andean region have good physical properties with regard to root penetration and soil structure. But improper land use and fertilizer management can lead to complete change in soil structure, building up soil crusting and sealing and finally increasing erosion and surface runoff through significantly reduced water infiltration. While the reasons for soil crusting and sealing on volcanic ash soils are not fully understood, promising results strengthen the hypothesis that an interaction between physical and chemical characteristics leads to this type of soil degradation. A better understanding of the processes influencing soil surface degradation will contribute to a more comprehensive view of soil erosion and its primary factors. This will help to make future recommendations for sustainable land use in this region.

The overall aim of this work is to investigate and characterize the phenomenon of soil crusting and sealing on volcanically influenced soils of the Andean region. This work is supported by special project funds from the DAAD/Germany and the Eiselen Foundation/Germany as well as the University of Hohenheim /Germany.

Materials and Methods:

Location: Field research was conducted at the Santander de Quilichao Research Station, Dep. Cauca of Colombia (3°6'N, 76° 31' W, 990 m.a.s.l). Trials were established on an amorphous, isohyperthermic, oxic Dystropept (Inceptisol). The field site has a bimodal rain distribution with two maximas in April-May and October-November, with a mean annual rainfall of 1799 mm, maximum intensity of rain up to 27.5 mm in 5 minutes and a mean annual temperature of 23.8°C.

The measurements on soil crusting were carried out on 27 Standard Erosion Experimental Plots (Wischmeyer Plots) that were originally designed by the soil conservation team from the University of

Hohenheim as completely randomized block in three repetitions. These plots have been used since 1986. Treatment history of the last eight years is presented in Table 2.

To the best of our knowledge, the research area represents the only integrated erosion demonstration and elaboration site in Latin America. The main advantage of this site is being monitored for the extent of soil erosion processes for the past 16 years. Thus any changes in soil structure resulting from this long period of cultivation, conservation and depletion can be easily investigated. Cassava (CIAT 383) was used as the main crop in different treatments to evaluate the impact of land use and fertilization.

Treatments: The treatments imposed since December 2000 are described in Table 3. Plots were limed before planting cassava with 500kg/ha dolomitic lime and chemical fertilized plots received 300 kg/ha mineral fertilizer (10N, 30P, 10K). Chicken manure from local poultry farms has been used. It had the following nutrient composition (% : N 1.8, P 2.38, K 2.87, Ca 10.58, Mg 0.64; ppm: Fe 2538, Mn 422).
Physical parameters: Ongoing research that began in 1999 is continued in 2001. Measurements included resistance to penetration, shear strength, rate of water infiltration, aggregate distribution and stability, texture, turbidimetrie, and percolation resistance. A Pocket Penetrometer (Model DIK-5560) was used for penetrometer measurements. Soil crusting and changes in soil surface hardening could be tested directly in the field. To analyze the shear strength a Hand Vane Tester (Model EL26-3345) was used in the field.

Chemical parameters: In addition to physical analysis, special emphasis was placed on analyzing the chemical properties of the soil. Preliminary tests showed a high correlation between electrical conductivity (EC) and soil hardening. Thus sub samples of each plot were analyzed for water soluble levels of K, Ca, Mg and Na by wet extraction. In addition to water soluble nutrients, exchangeable levels of K, Ca, Mg, Mn, Al and Fe were also measured. Finally the wet extract was used for EC measurements. Special attention was paid to EC because of high correlations between EC and several nutrients, penetration resistance and shear strength.

Infiltration: Rate of water infiltration was measured in April 2001 using a minisimulator. A fixed soil area (32.5 cm x 40 cm) was subjected to rain by a defined rain intensity class of 95 mm/h (deviation 5%) and surface run-off was measured. Infiltration was calculated through the difference between amount of rain and runoff.

Yield: Cassava root yield in December 2000 was measured to determine the impact of soil compaction process.

Table 2. History of treatments in Santander de Quilichao.

Treatment	93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01
1	Bare fallow	Bare fallow	Bare fallow	Bare fallow	Bare fallow	Bare fallow	Bare fallow	Bare fallow
2	Cowpea, mF[1]	Cassava oF4[2]	Maize oF4	Cassava oF4	Cowpea oF4	Maize oF4	Cassava oF4	Cassava oF4
3	Cassava	Cassava	Cassava	Cassava	Cowpea	Cassava	Cassava	Cassava
4	Bush fallow	Cassava mF	Maize mF	Cassava mF	Cowpea mF	Cassava mF	Cassava mF	Cassava mF
5	Br[4] P[5]	Cassava mF	Maize mF	Cassava mF	Cowpea mF	Maize mF	Cassava oF8[3]	Cassava oF8
6	Co mF(V)[9]	Cassava oF4(V)	Maize oF4(V)	Cassava oF4(V)	Cowpea oF4(V)	Maize oF4(V)	Cassava oF4(V)	Cassava oF4(V)
7	Cassava Ca[6]	Cassava Ca	Maize Ch[8]	Cassava Co	Cowpea mF	Maize Ch	Cassava Ch	Cassava Ch
8	Br P	Br P	Maize mF	Br Cm[7]	Br Cm	Maize Cm	Cassava mF	Br Cm
9	Bush fallow	Bush fallow	Bush fallow	Bush fallow	Bare fallow	Bare fallow	Cassava mF	Cassava mF

[1]mF = mineral Fertilizer.

[2]oF4 = organic Fertilizer. (Chicken manure, 4 t ha^{-1})

[3]oF8 = organic Fertilizer. (Chicken manure, 8 t ha^{-1})

[4]Br= *Brachiaria decumbens*

[5]P = *Pueraria phaseoloides*

[6]Ca = *Centrosema acutifolium*

[7]Cm = *Centrosema macrocarpum*

[8]Ch = *Chamaecrista rotundifolia*

[9](V) = Vetiver

Table 3. Treatments of 27 Experimental Plots in Santander de Quilichao in 2001.

Treatment	Plots			*Cultivation in-2001*
(1) Bare fallow	25	26	27	Raking at the beginning
(2) Cassava + 4t/ha chicken manure (trad.)	2	13	19	Rototiller, 4 t/ha chicken manure
(3) Cassava monoculture	3	11	24	Rototiller, no fertilizer
(4) Cassava minimum tillage	4	17	22	No tillage, min. fertilizer, Mulch
(5) Cassava + 8t/ha chicken manure	5	9	21	Rototiller, 8t/ha chicken manure
(6) Cassava+ 4t/ha chicken manure (Vetiver)	6	10	16	Rototiller, 4t/ha chicken manure
(8) Cassava rotation (*Brachiaria decumbens* + *Centrosema macrocarpum* in 2001)	8	14	18	Rototiller, min. fertilizer
(9) Cassava intensive tillage	28	29	30	Intensive Rototiller, min. fertilizer

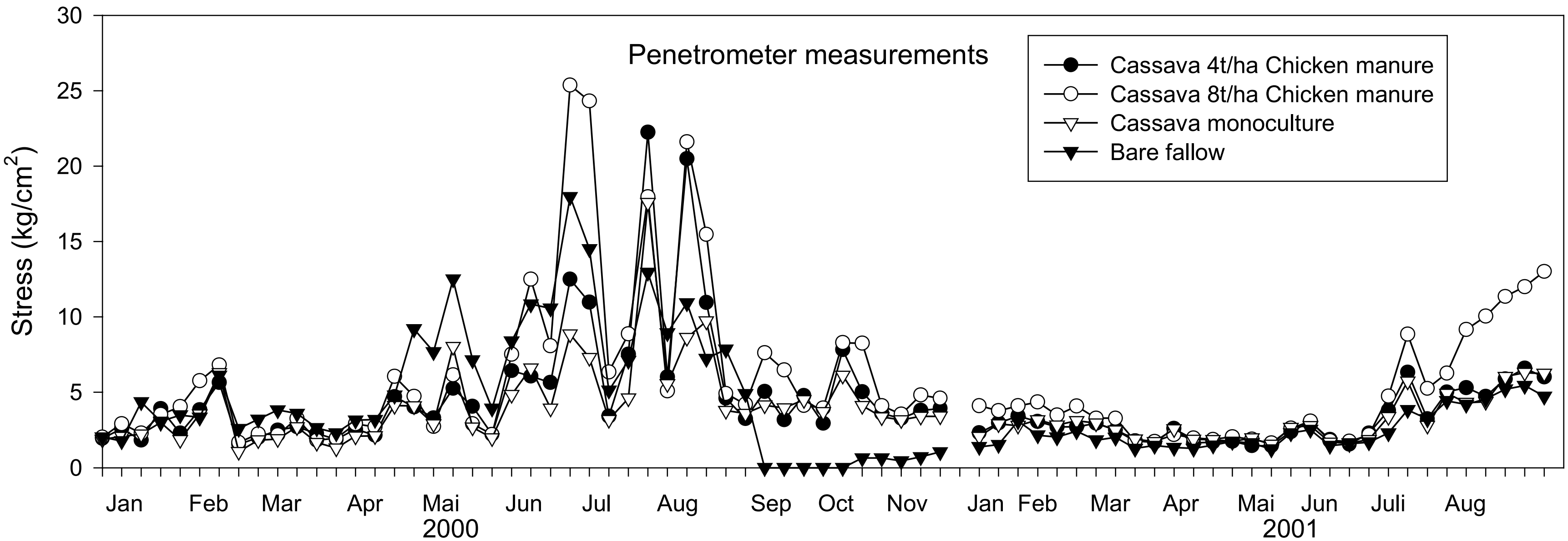
Results and Discussion:

Penetrometer and Torvane measurements: Throughout the entire measurement period (19 months) the Cassava minimum tillage treatment had the highest penetration resistance and shear strength. Untilled soil allows stable aggregates to build up, changing the penetration resistance over time. As already described in the PE-2 Annual Report (2000), soil hardening in Cassava minimum tillage treatment had no influence on water infiltration. In Cassava rotation plots, no strong hardening process could be observed in 2000 when Cassava had been cultivated. In 2001, Cassava was replaced by *Brachiaria decumbens* and *Centrosema macrocarpum*. This replacement lead to higher penetration resistance and shear strength, due to soil compaction.

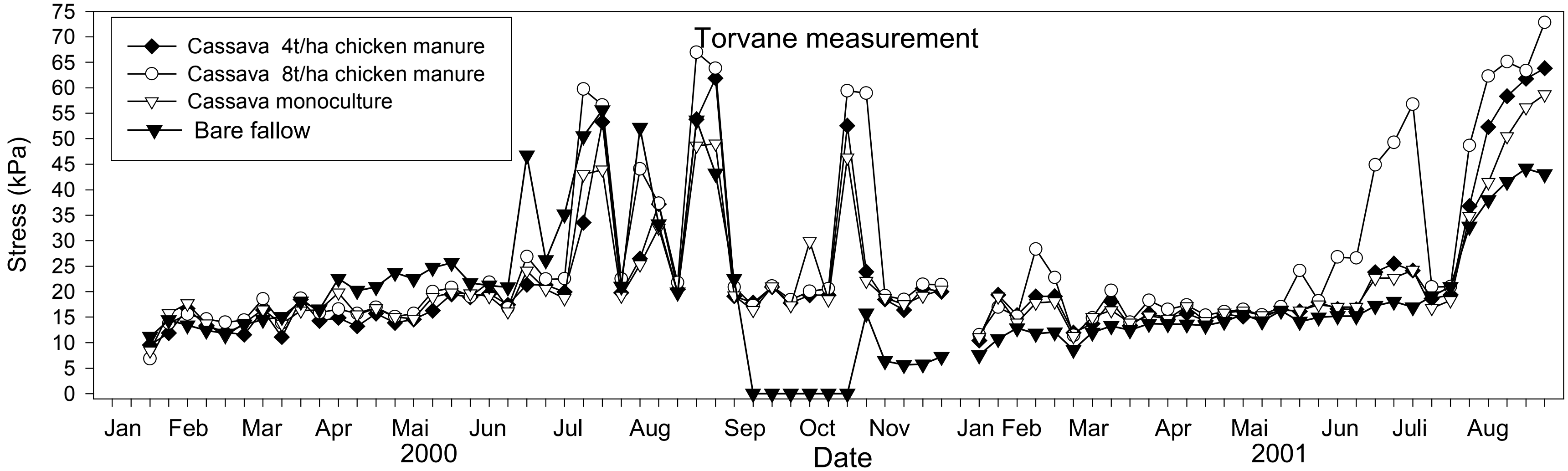
Results of Penetrometer and Torvane measurements on soil structural changes influenced by chicken manuring are presented in Figures 2 and 3. Two general differences were noticed for the time period after seedbed preparation, one with relatively wet soil conditions (Jan-Jun 2000) and another with very dry period (July-Oct 2000). These seasonal changes had a major influence on both penetration resistance and shear strength. In wet soil conditions no marked hardening process could be noticed. In dry season an increase of soil hardening was observed. Treatments with chicken manure notably turned into hardsetting soils, whereas Cassava 8t/ha chicken manure exceeded to Cassava 4t/ha chicken manure. Cassava monoculture and Bare fallow, which were not fertilized, showed lower penetration values and shear strength. A previously observed change into a single grain structure in these treatments became more obvious. At the beginning of September 2000, Bare plots had to be tilled to maintain a uniform Bare fallow status.

In 2001 similar results were observed. As soon as the soil dried in the main dry period (Jul-Oct) chicken manure plots turned from soft to hard.

Chemical Analysis: Results of chemical analysis are presented in Tables 4 and 5. Within the exchangeable nutrients the significantly highest concentrations of K were found in Cassava minimum tillage treatment, followed by chicken manure 8t/ha and 4t/ha. Significantly lowest concentrations of K values were observed in Bare fallow, Cassava monoculture and Cassava rotation. Similar results were observed with exchangeable Ca, Mg and Mn whereas Cassava 8/t/ha chicken manure had very low Ca concentrations and Cassava rotation had relatively higher Ca content. Minimum tillage treatment had significantly lower exchangeable Al and Fe while Bare fallow had the significantly greater Al content. Cassava rotation and Bare fallow showed greater levels of Fe content.



Penetrometer measurements
Cassava 4t/ha Chicken manure
Cassava 8t/ha Chicken manure
Cassava monoculture
Bare fallow
Stress (kg/cm^2)
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
Mai
Jun
Jul
Aug
Sep
Oct
Nov
2000
Jan
Feb
Mar
Apr
Mai
Jun
Juli
Aug
2001



Figures 2 and 3. Effects of chicken manure on penetration resistance and shear strength, Santander de Quilichao, 1/2000-8/2001

Table 4. Effect of different treatments on exchangeable K, Ca, Mg. Al, Fe and Mn, Santander de Quilichao, Feb 2001

Soil depth (cm)	Treatments	Exchangeable Nutrients					
		K	Ca	Mg	Al	Fe	Mn
		------------ cmol kg^{-1}------------			------------ mg kg^{-1} ------------		
0-5	Bare fallow	0.08 a	0.09 a	0.03 a	1.48 c	17.24 b	1.27 a
0-5	Cassava 4t/ha chicken manure	0.29 c	2.17 d	0.69 c	0.09 a	10.56 a	8.59 c
0-5	Cassava monoculture	0.16 b	1.04 b	0.38 b	0.55 b	13.00 a	5.33 b
0-5	Cassava minimum tillage	0.42 d	3.29 e	0.92 d	0.07 a	9.53 a	8.89 c
0-5	Cassava 8 t/ha chicken manure	0.35 cd	1.30 bc	0.45 b	0.54 b	12.79 a	6.75 b
0-5	Cassava rotation	0.17 b	1.63 c	0.37 b	0.46 b	17.46 b	6.47 b

Means followed by different letters within the column are significant at 0.05-probability level (Duncan test).

Water soluble K levels were greater with Cassava minimum tillage followed by 8 t/ha chicken manure, 4 t/ha chicken manure, Cassava Rotation, Cassava Monoculture and Bare fallow (Table 5). Similar results were obtained for Ca, Mg and Na. Only Cassava rotation had Ca and Na values as high as Cassava 8 t/ha Chicken manure. Significantly greater EC values (0.36 mS) were observed with Cassava minimum tillage followed by Cassava 8 t/ha, Cassava rotation and Cassava 4 t/ha. Lower values of EC were observed with Cassava monoculture and Bare fallow (0.11 mS).

Table 5. Effect of different treatments on water soluble K, Ca, Mg, Na and electrical conductivity, Santander de Quilichao, Feb 20001.

Soil depth (cm)	Treatment	Water soluble nutrients				Electric conductivity EC
		K	Ca	Mg	Na	
		------------------- mg kg^{-1}-------------------				------- mS ------
0-5	Bare fallow	1.82 a	3.31 a	0.89 a	4.86 a	0.11 a
0-5	Cassava 4 t/ha chicken manure	4.45 b	12.10 bc	4.07 c	5.46 ab	0.21 b
0-5	Cassava monoculture	2.28 a	7.16 ab	2.24 ab	5.32 ab	0.14 a
0-5	Cassava minimum tillage	8.13 c	26.51 e	7.76 e	7.68 d	0.36 c
0-5	Cassava 8 t/ha chicken manure	7.05 c	13.04 bc	4.14 d	6.22 bc	0.24 b
0-5	Cassava rotation	2.92 ab	16.47 d	3.48 b	6.48 c	0.23 b

Means followed by different letters within the column are significant at 0.05 probability level (Duncan test).

A closer relationship was observed between electric conductivity (EC) and some of the above mentioned nutrients. Results of these relationships are presented in Figure 4. The highest correlation was found between EC and water soluble Ca and Mg. Correlations between EC and soluble K and Na were lower. In addition, positive correlations between EC and exchangeable Ca, K, Mg and Mn were found. Exchangeable Al and Fe had no correlation with EC.

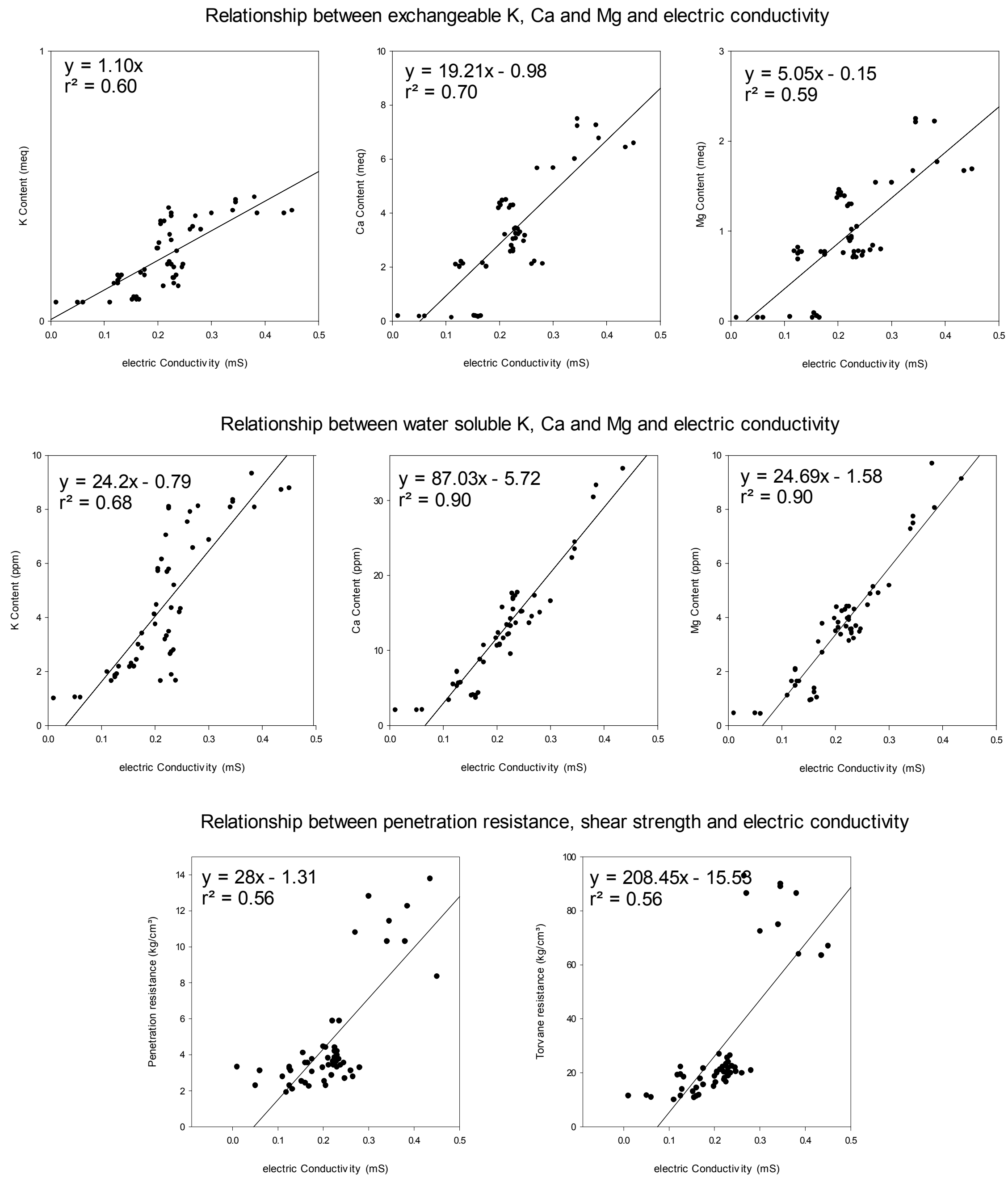


Figure 4. Relationship between electrical conductivity and other soil characteristics (exchangeable K, Ca, Mg, soluble K, Ca, Mg, penetration resistance and shear strength), Santander de Quilichao, Feb 2001.

Correlation between EC and the above mentioned stability factors, penetration resistance and shear strength were of great interest. It was revealed that correlations between EC and these two factors were identical. One remarkable fact is that the Cassava minimum tillage treatment accumulated nutrients, causing a high EC to occur. However, conventionally tilled treatments had lower EC values. The Monoculture and the Bare fallow treatments had the lowest EC values as well as the lowest hardening process at the soil surface.

The dissolving capacity of positively charged chicken manure, such as in Cassava 8 t/ha chicken manure plots, has a strong influence on volcanic ash soils with high clay content. If the soil comes into contact with the fertilizer, nutrients like Na and K tend to dissolve stable soil aggregates by peptization, finally causing clay dispersion. After high amounts of rain, the soil solution is either washed out horizontally by surface run-off, or washed in vertically creating the so called soil sealing. After drying, the crusting process can be observed.

Therefore, the key reasons for soil crusting on volcanic ash soils as found in Santander de Quilichao are the wet and dry seasons and their interaction with organic manuring. The effects on the dissolving and hardening processes are shown in Figures 2 and 3.

For Cassava planted in December, root growth is significantly limited because of these processes, as seen in chicken manure plots and especially the Cassava 8 t/ha plot. High correlations between K, Ca, Mg, Na and electrical conductivity, as well as correlations between penetration resistances, shear strength and electrical conductivity, make it obvious that both chemical and physical constraints are the reasons for the crusting process.

In general, Cassava minimum tillage techniques allow nutrients to be accumulated over time. These nutrients are mainly derived from mineral fertilization and additional mulch. A hardening process does occur (as mentioned above) but the minimum tillage treatment maintains the soil's structural stability, as is evident from infiltration measurements. Cassava minimum tillage and Cassava rotation had greater exchangeable and water soluble Ca contents. Ca contributes to a stable surface structure, as is evident with high values of penetration resistance, but had no influence on water infiltration process. The Cassava monoculture treatment did not have any of these stability agents. A real crusting process was not evident with this treatment. The weak soil structure prevents this treatment from developing a good draining pore system. Infiltration was very low compared to other treatments, resulting in soil erosion in Cassava monoculture as well as in Bare fallow.

Infiltration: Results on infiltration measurements are presented in Figure 5 and Table 6. Generally, high water infiltration in all treatments was observed. This was expected due to good physical structure of these soils. The goal of this research was to find out whether change in land use over time has an influence on water infiltration. Cassava rotation and Cassava minimum tillage had the highest rates of water infiltration for all treatments. As already described before (PE-2 Annual Report, 2000), improved stability of soil aggregates is the reason for this phenomenon. Although Cassava minimum tillage had the greatest penetration resistance, shear strength and water infiltration rate were not influenced by compaction. Continuous fallow crop rotation had a positive influence on water infiltration. The root system of pasture grass contributes to a highly effective soil pore system that results in high water infiltration capacity.

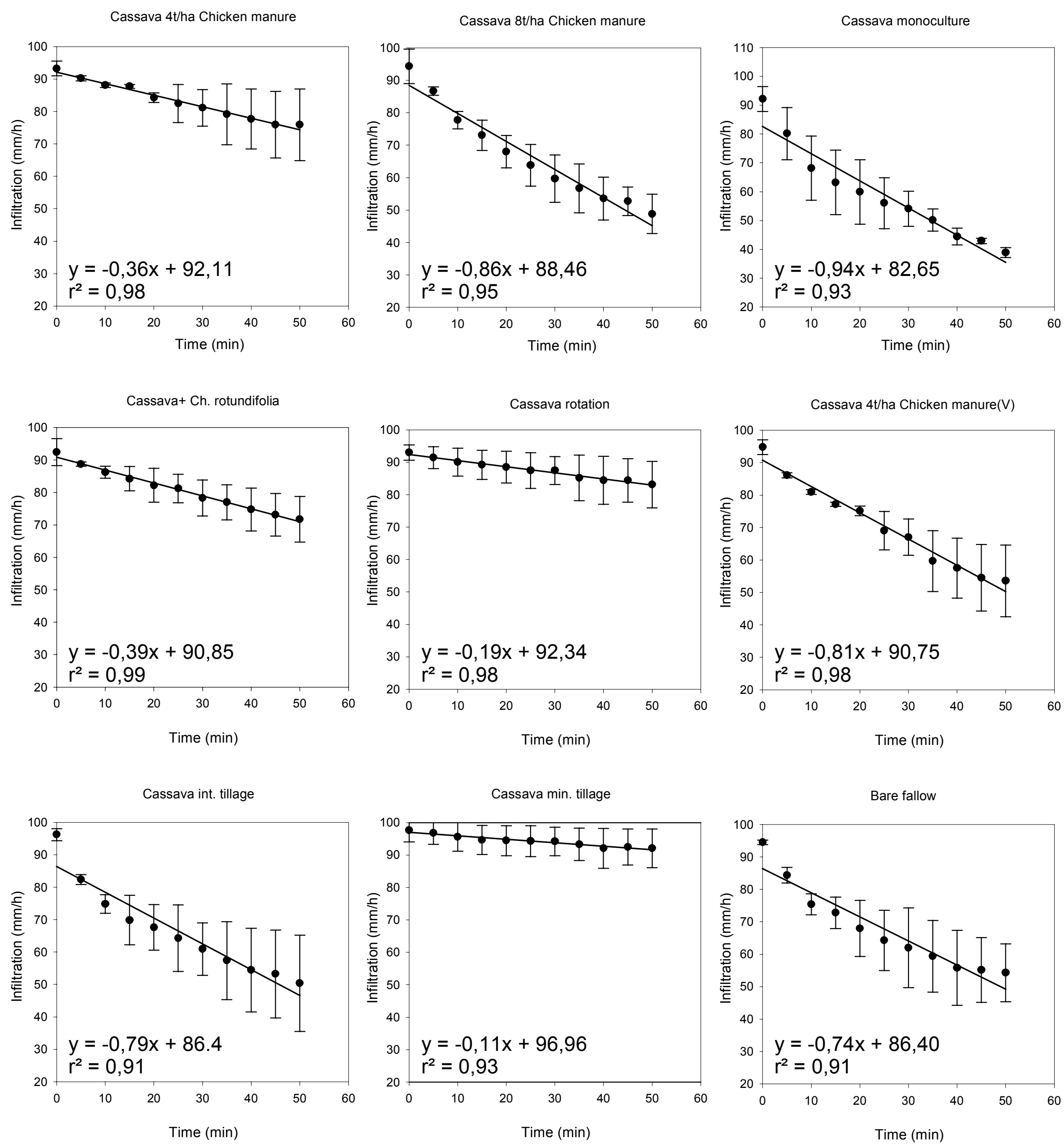


Figure 5. Dynamics of water infiltration measured by minirainsimulation in different land use systems, Santander de Quilichao, April 2001.

Table 6. Influence of different treatments on water infiltration measured by a minisimulator, Santander de Quilichao, April 2001.

No.	Treatment	Water Infiltration (mm/h)	Run-off (mm/h)	Rain Intensity (mm/h)
1	Bare fallow	54.3 a	40.2 b	94.5
2	Cassava 4 t/ha chicken manure	75.9 b	17.3 a	93.2
3	Cassava monoculture	38.9 a	53.2 b	92.1
4	Cassava minimum tillage	92.0 c	5.6 a	97.6
5	Cassava 8t/ha chicken manure	48.8 a	45.5 b	94.3
6	Cassava 4 t/ha chicken manure (Vetiver)	53.6 a	41,3 b	94.8
7	Cassava + *Chamaechrista rotundifolia*	71.7 b	20.7 a	92.4
8	*B. decumbens* + *C. macrocarpum*	83.1 bc	9.9 a	93.0
9	Cassava intensive tillage	50.4 a	45.8 b	96.2

Means followed by different letters within the column are significant at 0.05 probability level (Duncan test).

The lowest infiltration was observed with Cassava monoculture, Cassava intensive tillage, Cassava 8 t/ha chicken manure, and Bare fallow. The main reasons for this are the impact of raindrops (splash impact) and poor aggregation, as well as reduced permeability due to chemical dispersion. A stable aggregate system, either through long-term aggregation or root biomass, contributes to high rates of water infiltration rates. If aggregate breakdown occurs, as observed in Cassava monoculture or Cassava intensive tillage, infiltration could be strongly reduced.

Harvest: Results of cassava harvest data are presented in Table 7 and Figure 6. Overall the best root yields were found in Cassava 4t/ha chicken manure and Cassava rotation. Reasons for high Cassava root yields in these treatments are due to improved soil conditions such as moderate soil hardening, sufficient fertilization, enhanced soil aggregation and high water infiltration. In contrast, the lower yields were found with Cassava monoculture and Cassava intensive tillage treatments.

Table 7. Cassava root yields, Santander de Quilichao, 2000.

Treatment	Yield (t/ha)
Cassava monoculture	4.33 a
Cassava int. Tillage	11.98 b
Cassava + *Chamaechrista rotundifolia*	21.05 c
Cassava (V) 4t/ha chicken manure	21.90 c
Cassava 8 t/ha chicken manure	23.17 cd
Cassava minimum tillage	27.01 cd
Cassava rotation (*Brachiaria decumbens* + *Centrosema macrocarpum*)	30.59 e
Cassava 4 t\ha chicken manure	30.92 e

Means followed by different letters within the column are significant at 0.05 probability level (Duncan test).

The single grain structure and low water infiltration capacity contributed to low root yield. The intensive tillage treatment caused a breakdown of the soil aggregates, reduction in soil pore system and less water intake, thereby leading to reduced yields. In both treatments, roots were very small and economically worthless. Cassava 8 t/ha chicken manure treatment had high amounts of plant biomass but hard soil structure, preventing optimal development of Cassava roots. In Cassava minimum tillage treatment, root growth was limited to the area of soil that was loosened before planting. Therefore yields in both treatments were lower than in Cassava rotation and Cassava 4 t/ha chicken manure.

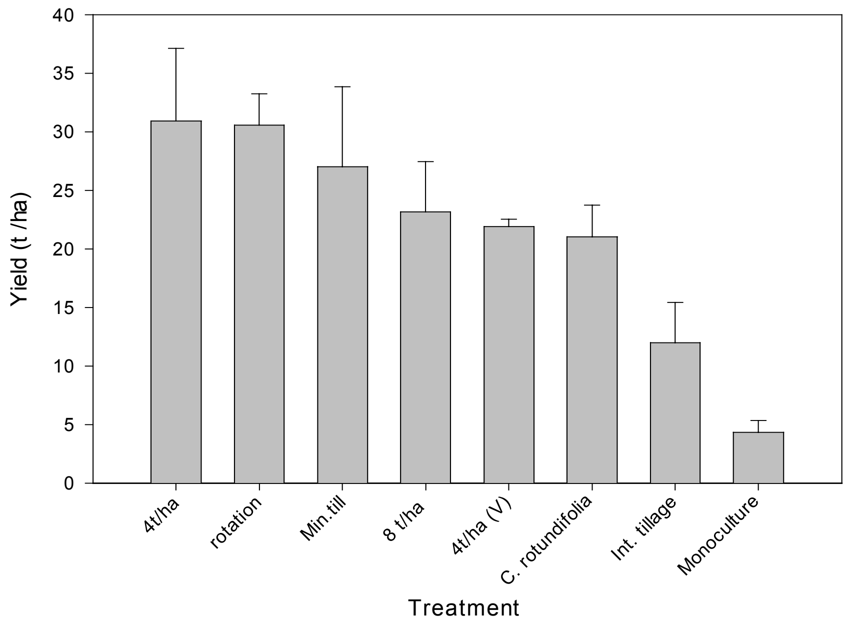


Figure 6. Effect of different treatments on cassava root yield, Santander de Quilichao, Dec 2001.

Impact:

Some general conclusions can be made, although field research is not yet completed. Excessive organic manuring, of up to 12 t/ha chicken manure in the Cauca, leads to a deterioration of soil stability. Soils fertilized with organic chicken manures have more crusting symptoms than other soils. There is a seasonal change in soil crusting and sealing. In the wet season especially, fertilized plots dissolve stable soil aggregates. A hardening process can be observed during dry season. Soil hardening does not necessarily reduce the infiltration capacity of a treatment, as the status of aggregation and stability factors like root growth have to be taken into account. This can be observed with Cassava minimum tillage and Cassava rotation. Therefore, the factors that lead to positive results with regard to soil fertility, soil water status, plant growth, and yield need to be determined, as does the extent to which compaction has a negative impact on root development. High correlations observed between electrical conductivity and several soil parameters indicates that further research work is needed to determine the influence of cations on soil crusting and sealing, and their physical and chemical interactions during dry and wet seasons. Effects of clay dispersion due to Na and K also need to be analyzed in order to strengthen the hypothesis that both nutrients are the key factors contributing to dispersion of soil particles and crusting in chicken manure treatments. We need to find out to what extent and at what intensity chicken manuring can be promoted without damaging the soil surface structure because it must be taken into account that organic fertilizers are cheap and useful for the stakeholders. The main challenge for sustainable land use of Andean hillsides should therefore be to find out the appropriate level of manure application together with proper recommendations of soil management.

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1.1.3 Developing methods to predict spatial and temporal variation in rainfall distribution for the Llanos of Colombia

Highlight:

- Developed a method to predict precipitation (including intermittent drought) for seven consecutive days for soils of different texture.

Purpose:

To develop methods to predict precipitation within seven consecutive days for soils of different texture for the Altillanura region based on climate data records kept at two meteorological stations, Carimagua and La Libertad.

Rationale:

In developing countries most crops are cultivated under rainfed conditions. However, for a better planning of rainfed agriculture, knowledge on probabilities of rainfall in relation to water requirements for crop production is essential for proper use of this important natural resource.

Traditionally in Colombia, the meteorological information is processed through statistical analyses such as the mean, which could mask the extent of variability particularly for rainfall. Since rainfall is a major determinant of crop productivity, it is essential to know the extent of its spatial and temporal variation for the benefit of improved crop performance under rainfed conditions. Therefore, it is important to develop tools to predict rainfall distribution for different soil types of Altillanura using improved statistical models. This will help to develop improved soil and water management strategies for the region.

Materials and Methods:

The study area is located in the Eastern plains of Colombia (Orinoquia river basin). Climate data records that were kept at two meteorological stations: Carimagua (4° 36' L.N, 71° 10' L.W) (1975 to 1997) and La Libertad (4°04' L.N, 73° 29' L.W) (1974-1998) of the Eastern Plains of Colombia were used for the study. The soils in the well-drained region correspond to Oxisols and Ultisols with clay, clay-loam, sandy-loam and sandy soil texture. These soils are acid, infertile with high Al saturation and low organic matter content.

Climate databases of Carimagua and La Libertad research stations were used with the following objectives:

- Analyze the climatic information available at daily, weekly and monthly intervals to predict rainfall probabilities.
- Estimate the probabilities of occurrence of wet and dry days in both locations.
- Estimate soil water balances of the zone of influence of both research stations.

The following statistical distribution methods were used:

- Normal distribution: for yearly and monthly rainfall.
- Binomial distribution: for daily distribution.
- Gamma distribution: for weekly and monthly distributions.

In order to calculate the probabilities of consecutive dry or wet days, the methodology of Feyerhem and Bark was followed, with some modifications to fit it to statistical concepts.

The following equations were used:

$P(D_t)$: number of year the (t)th day was dry (D) divided by the number of years of record.
$P(W_t)$: $1 - P(D_t)$

$P(D_t/D_{t-1})$: number of years that the (t)th and (t-1)st days were dry divided by the number of years that the (t-1)st was dry.

$P(W_t/D_{t-1})$: $1 - P(D_t/D_{t-1})$

$P(W_t/W_{t-1})$: number of years that the (t)th and (t-1)st days were wet (D) divided by the number of years that the (t-1)st was wet.

$P(D_t/W_{t-1})$: $1 - P(W_t/W_{t-1})$

The sum of the probabilities for all possible sequences equals unity. Table 8 shows an example of the dry and wet daily probabilities for the month of July in Carimagua:

Results and Discussion:

The rainfall behavior for the two locations (Carimagua and La Libertad) is unimodal. The dry season occurs from November to March and the wet season is from April to October. The model of gamma distribution used for the description of the rainfall data in both localities showed unimodal behavior as expected. For improved crop performance, it is important to be able to predict the intermittent droughts that could occur at critical stages of crop development. This would require the ability to predict spatial and temporal variability in rainfall distribution within a week or less. Using the gamma distribution method, we found that the probabilities of rainfall have their maximum during the month of July with a value of 0.9 (90%) for Carimagua and of May for La Libertad with 0.9, and its minimum with 0.0 in January for both locations. This information is very useful to develop recommendations for planting and soil and water management for different crops that can be cultivated in the Altillanura region of the Orinoco river basin.

July	D	W	D/D	W/D	D/W	W/W
1	0.2	0.8	0.0	1.0	0.2	0.78
2	0.1	0.9	0.0	1.0	0.1	0.89
3	0.3	0.7	0.0	1.0	0.3	0.67
4	0.1	0.9	0.3	0.7	0.1	0.94
5	0.2	0.8	0.0	1.0	0.3	0.75
6	0.2	0.8	0.4	0.6	0.2	0.83
7	0.2	0.8	0.4	0.6	0.2	0.83
8	0.2	0.8	0.6	0.4	0.1	0.89
9	0.2	0.8	0.2	0.8	0.2	0.83
10	0.3	0.7	0.5	0.5	0.2	0.79
11	0.2	0.8	0.3	0.7	0.2	0.78
12	0.2	0.8	0.0	1.0	0.2	0.78
13	0.3	0.7	0.3	0.8	0.3	0.74
14	0.3	0.7	0.0	1.0	0.4	0.65
15	0.3	0.7	0.5	0.5	0.2	0.82
16	0.1	0.9	0.2	0.8	0.1	0.88
17	0.2	0.8	0.3	0.7	0.2	0.8
18	0.3	0.7	0.2	0.8	0.3	0.67
19	0.3	0.7	0.3	0.7	0.3	0.75
20	0.1	0.9	0.3	0.7	0.1	0.94
21	0.2	0.8	0.3	0.7	0.2	0.85
22	0.3	0.7	0.5	0.5	0.3	0.68
23	0.1	0.9	0.3	0.8	0.1	0.87
24	0.3	0.7	0.3	0.7	0.4	0.65
25	0.3	0.7	0.5	0.5	0.1	0.87
26	0.3	0.7	0.3	0.7	0.3	0.71
27	0.4	0.6	0.5	0.5	0.4	0.65
28	0.3	0.7	0.4	0.6	0.1	0.86
29	0.3	0.7	0.0	1.0	0.4	0.65
30	0.1	0.9	0.5	0.5	0.0	1
31	0.2	0.8	0.3	0.7	0.2	0.85

Table 8. Rainfall probabilities for dry (D) or wet (W) days for the month of July in Carimagua. D/D = probability of a dry day following a dry day; W/D = probability of a dry day following a wet day. D/W = probability of a wet day following a dry day. W/W = probability of a wet day following a wet day.

Impact:
The methodology developed from this study could be applicable to other climatic areas where rainfed agriculture is practiced. The knowledge of sequence of dry or wet days is very useful for defining farm operations such as time of land preparation and dates of sowing and harvesting for different crops.

Contributors:
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Activity 1.2 Survey native plants and their potential use as biofertilizers

Activities initiated in Nicaragua as part of new collaboration with Universidad Centro Americana (UCA) will be reported next year.

Activity 1.3 Survey land users for soil and crop management knowledge

1.3.1 Implications of local soil knowledge for integrated soil fertility management

Highlight:
- Surveyed land users in Colombia and Honduras for local knowledge about soils and their management and identified native plants as important indicators of soil quality related to modifiable soil properties.

Purpose:
To determine the complementary nature of local and scientific knowledge to develop an overall strategy for sustainable soil management.

Rationale:
Local knowledge related to agriculture can be defined as the indigenous skills, knowledge and technology accumulated by local people derived from their direct interaction with the environment. It is the result of an intuitive integration of local agroecosystem responses to climate and land use change through time. Transfer of information from generation to generation undergoes successive refinement leading to a system of understanding of natural resources and relevant ecological processes.

There is increasing consensus about the need for enhanced understanding of local knowledge in planning and implementing development activities. The slow rate of assimilation of new technology and new cropping systems has been often attributed to local inertia rather than the failure to take into account the local experience and needs. The 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. Besides, ethical considerations related to participation and empowerment of local communities have gained considerable importance.

The complementary role that indigenous knowledge plays to scientific knowledge in agriculture has been increasingly acknowledged. Experimental research is an important way to improve the information upon which farmers make decisions. It is questionable, however, if relying on experimental scientific methodology alone is the most efficient way to fill gaps in current understanding about the sustainable management of agroecosystems. There has been limited success of imported concepts and scientific interpretation of tropical soils in bringing desired changes in tropical agriculture. This has led to an increasing recognition that the knowledge of people who have been interacting with their soils for long time can offer many insights about managing tropical soils sustainably.

Nevertheless, although benefits of local knowledge include high local relevance and potential sensitivity to complex environmental interactions, without scientific input local definitions can sometimes be inaccurate and unable to cope with environmental change. It is thus argued that a joint local/scientific approach, capitalizing on complementarities and synergies, would permit overcoming the limitations of site specificity and empirical nature and allow knowledge extrapolation through space and time.

This work examined two case studies on local soil knowledge and management and the implications of these results on future research on integrated soil fertility management (ISFM). ISFM refers to the broad definition of soil fertility that includes the chemical, physical and biological factors affecting the productive potential of the soil. While ISFM involves managing the widest variety of possible sources of fertility and rely as much as possible on local knowledge and decission making, it also uses research-based understanding and analysis of the underlying soil processes.

Results from case studies to elicit local information using key-informants are reported for small farmers from the Cabuyal river watershed in Cauca, Colombia. A participatory approach was used with six farmer communities from the Tascalapa river watershed in Yoro/Sulaco, Honduras, in order to identify and classify local indicators of soil quality related to permanent and modifiable soil properties. Finally, the potential of the latter approach as a mechanism for consensus building that facilitates ISFM in the landscape is discussed.

Materials and Methods:

Case studies

Andean hillside farmers from Colombia: Studies on local knowledge about soils and their management were conducted within the Cabuyal watershed, Cauca department – Colombia using case study approaches with semi-structured questionnaires, participatory farm mappings of soil qualities and identification of local indicators used to discriminate among different soils. Previous studies in the area by CIAT (Centro Internacional de Agricultura Tropical) during the last 15 years facilitated the identification of key informants from each village. Key informants were selected from eight villages in three altitudinal zones in the watershed. High elevation villages (1700-2200 m.a.s.l.) included: El Cidral, La Esperanza, La Primavera and El Rosario, middle elevation villages (1450-1700 m.a.s.l.) La Campiña and El Porvenir, and low elevation villages (1175-1450 m.a.s.l.) included La Llanada and La Isla. In the predominantly young volcanic-ash soils (Oxic Dystropepts), 100% of farmers interviewed use soil color for classification and assessment of soil quality. Black colored soils are considered good for cropping and yellow and red soils are considered marginal. Black soils are often found in soils under forest, fallow or pastures. Increasing use of tillage has lead to increased rates of soil erosion and loss and thus the usually darker top-soil has given way to the red sub-soil where cultivation is now taking place in many agricultural plots.

Results and Discussion:

Native plants constitute another means by which Andean hillside farmers classify the soils in their farms. In Table 9 we find native plants used as indicators of soil quality by farmers in the Cabuyal river watershed. Fertile soils are characterized by trees like 'nacedero' (*Trichanthera gigantea*) and 'guamo' (*Inga sp*.) and herbaceous plants like 'papunga' (*Bidens pilosa*) and 'mariposo'(Clibadium surinamensis) while plants predominating in poor soils invariably include 'helecho marranero' (*Pteridium aquilinum*) and 'paja garrapatera' (*Andropogon bicornis*). Farmers also identify ubiquitous species such as 'yaraguá' (*Mellinis minutiflora*) and 'caracola' (*Koheleria lanata*) which are then characterized by their vigor and leaf color. Darker green colored leaves are associated with more fertile soils while yellowish colors are indicative of poor soils.

Table. 9 Most important plant species used as local indicators of soil quality by Cabuyal watershed hillside farmers, Colombia

Common name	Scientific name	Botanical family	Plant type**	Soil type
Papunga	*Bidens pilosa*	Asteraceae	H	Fertile
Mariposo	*Clibadium surinamensis*	Asteraceae	H	
Margarita	*Chaptalia nutans*	Asteraceae	H	
Mortiño	*Clidemia hirta*	Meliaceae	H	
Altusara	*Phytolacca americana*	Phytolaccaceae	H	
Siempre Viva	*Commelina difusa*	Commelinaceae	H	
Hierba de chivo	*Ageratum conyzoides*	Asteraceae	H	
Nacedero	*Trichantera gigantea*	Acanthaceae	T	
Cachimbo	*Erythrina* sp	Leguminosae	T	
Guamo	*Inga* sp	Leguminosae	T	
Helecho marranero	*Pteridium aquilinum*	Pteridiaceae	H	Poor
Paja garrapatera	*Andropogon bicornis*	Poaceae	H	
Paja blanca	*Andropogon leuchostachys*	Poaceae	H	
Helechillo	*Dichranopteris flexosa*	Pteridaceae	H	

** Plant type: H = herbaceous, T = tree.

Soils are also classified by their structure into 'polvoso' or "powdery", that is, with no macroaggregates indicating degraded soils on the one hand, and 'granoso' or "grain-like" which indicates some level of aggregation associated with better soils. This is an important characteristic used by farmers to assess soil recuperation after degraded soils have been left uncultivated to "rest" or fallow. In these hillside soils, topographic position also plays an important role in local soil classification. Hill tops or 'cimas'are identified as containing poorer soils, while the quality of hillsides or 'lomas' depends on how steep the slope is. The more fertile soils are concentrated in the flat areas or 'planadas', hollowed areas or 'huecadas' because of the accumulation of eroded soils lost from up the hill as well as riverine floodplains by deposition of nutrient rich sediments. Inherently infertile soils are named 'tierra brava' or "angry soils" which should be distinguished from 'tierra cansada' or "tired soils" which are soils degraded by inappropriate management. Farmers consider that while the former are likely to respond to fertilizer applications (i.e. chicken manure) the latter invariably needs a period of fallow phase to recover lost attributes.

Central American hillside farmers from Honduras: A participatory approach was used in Honduras to identify and classify local indicators of soil quality and details can be found in Trejo et al. (1999) and activity 3.2.1 in this report. In short, six communities were selected from the Tascalapa watershed, namely Santa Cruz, Mina Honda (higher zone), San Antonio, Jalapa and Luquigue (middle zone) and Pueblito (lower zone) to identify and classify local indicators of soil quality at a landscape scale. Brainstorming sessions with farmer groups from the six communities respectively were followed by a prioritization phase where farmers from each community were split into smaller groups in order to rank local soil quality indicators identified according to their relative importance using paper cards. The final list of local indicators, in order of importance, was then integrated with their corresponding technical indicator in plennary sessions and organized into indicators of permanent (Table 10) and modifiable (Table 11) soil properties.

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.

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.

Key permanent soil properties captured by local indicators that are commonly perceived as important by farming communities included slope, soil depth, soil color, soil texture and soil structure. The importance of slope in this hillside environment is obvious as there is a maximum inclination under which agriculture can be practiced. Because of their topography, hillside soils are prone to erosive processes even under natural vegetation or appropriate management. These soils tend to be relatively shallow compared to valley soils and therefore local farmers identify a minimum soil depth required for crop root growth and development (i.e. 12 inches, half a cutlass). Soil color provides a good measure of inherent soil fertility where black soils are seen as good soils and other red and yellowish colors as poor soils. Nevertheless, despite being classified as a permanent property, local farmers recognize that management practices involving crop residue additions could darken light colored soils indicating improvement in their quality. The importance of soil texture is perceived by local farmers as affecting soil water holding capacity as well as the resistance to tillage. Soil workability is also related to soil structure as good soils are perceived as those that do not compact, and where soil aggregates can be broken by tillage.

Modifiable soil properties of importance were perceived as those related to the lack or presence of burning, the type of native vegetation and the soil biological activity indicated by the presence of soil organisms (i.e. earthworms). Fire as an agricultural management tool has been probably used by the earliest farmers as a way to recover nutrients in the native vegetation biomass for the crops, to control pests and to dispose of perceived "excess" plant biomass in the fields. Despite the realization of the harm done by annual fires to the soil, the lack of farmer consensus that could lead to a concerted action appears to be an important limitation. The participatory methodologies presented here have the potential to facilitate consensus amongst the local farmer community on high priority problems and opportunities. In this capacity, their linkage to concrete plans of action suggests this participatory approach as a way to promote collective action at a landscape scale.

Table 10. Integration of local and technical indicators of soil quality related to permanent soil properties in contrast sets identified and ranked according to their importance by Honduran hillside farmers from different villages.

	Knowledge Integration					
Ranking	Santa Cruz	Mina Honda	Jalapa	San Antonio	Luquigue	Pueblito
1	High water retention/ low water retention. (Texture/ water holding capacity)	Spongy, "espolvoreado", not sticky/"Arenisca", hard, sticky. (Texture)	Thick soil layer/thin soil layer. (Soil depth)	Deep or thick soil/ thin soil. (Soil depth)	Soil thickness of at least 12 inches, 2 palms, half a cutlass/thin soil less than 4 inches. (Soil depth)	Flatlands/ "Tierras quebradas" broken lands. (Slope)
2	Thick top soil/thin top soil. (Soil depth)	Soil with a thick fertile layer/ "frierra", when fertile layer is very thin or absent. (Soil depth)	Soils with gentle slopes, uniform/soils with high slopes. (Slope)	Black color/Light color, yellowish, reddish. (Color)	Good holding of water, soil that absorbs water/ low water retention. (Texture/water holding capacity)	Thick soil layer/thin soil layer, "delgadita". (Soil depth)
3	Blackish/light colors. (Color)	"Tierra tendida", "poca falda", little slope/"Guindo", "abismo", steep slopes. (Slope)	Soil keeps water for longer time/soil does not keep water. (Texture/water holding capacity)	Good plow penetration/limited plow penetration. (Physical barriers)	Easy to plow/difficult, needs skill to plow. (Physical barriers)	"Harinita", flour like, "huestesita"/ clay soil, sandy soil. (Texture)
4	Flatter lands/"Tierras quebradas", broken lands. (Slope)	Black color/"colorada", reddish, "amarilla", yellowish. (Color)	Black/various soil colors. (Color)	Few stones/plenty of large stones or "lajas". (Stoniness)	Black color/Yellow color, "moreno", tan, "colorada", reddish. (Color)	Black soils/Reddish soils, "medias coloradas". (Color)
5	Many stones/few stones. (Stoniness)	"Suelos francos", loamy soils/ "barriales",clay, mud, "arenoso", sandy. (Texture)	Fast water absorption/ slow water absorption, (Texture/infiltration)	Little slope/steep slope or "falda". (Slope)	Loose rocks on topsoil, not many stones/know-ledge of rocks below topsoil by inserting machete. (Stoniness)	Could have small stones/have big stones. (Stoniness)
6		Small stones and few/ Many stones. (Stoniness)	Loamy soils, little clay/ "Brarrialosa"or muddy, sandy. (Texture/particle size)	Loams "francos"/ "Barrialosa", muddy, much sand. (Texture)	"Suelos francos", loamy soils/"areniscas", sandy soils, "barrilosas"or clay soils. (Texture)	"No se ende", not a cracking soil/"Se ende", cracking soil. (Clay type)
7			Easy tillage/difficult tillage, "Tronconosa". (Physical barriers)	"No se ende", non-cracking soils/"Se ende", cracking soils. (Clay type)	"No se ende", non-cracking soils/"Se ende", cracking soils. (Clay type)	
8			No stones present/ "Balastrosa", stony, gravely. (Stoniness)			

*Ranking values are inversely related to degree of importance (i.e. 1 = highest importance).

Table 11. Integration of local and technical indicators of soil quality related to modifiable soil properties in contrast sets identified and ranked according to their importance by Honduran hillside farmers from different villages.

	Knowledge Integration					
Ranking	Santa Cruz	Mina Honda	Jalapa	San Antonio	Luquigue	Pueblito
1	Fertile soil / Non-fertile soil. (Fertility)	“Revenideros”, washed land, “tierra lavada”/ “Tierra no lavada”, unwashed land. (Erosion)	“Opulento”, no need of chemical fertilizer/ needs fertilization. (Soil fertility)	“Opulento”, high fertility / low fertility. (Soil fertility)	Good plants, good crop, lush and thick plants / Bad plants, bad crops. (Vegetation type / Yield)	Soil is not poddled, “no se aguachina”/soil is poddled, “se aguachina”. (Drainage)
2	Organic residue in-corporation of organic residues. (Soil organic residues)	Good yields given/Bad yields given. (Yield)	Presence of earth-worms/lack of earthworms. (Biological activity)	“Verdolaga”, “quilete”, “chichiguaste”, “chango”, “Pica pica”, “guama” / “tatascán”, “Pino”. (Indicator plants)	Land with “chichiguaste” and malva/land with “zacate” or native pasture. (Indicator plants)	Soil incorporated/ washed soil. (Erosion)
3	“Tierra blanda”, soft soil, “suelta”, loose/ “Tierra amarrada”, tied soil. (Structure)	“Buenos guamiles”, good fallows, / “Rastrojito”, “bajillales”, small fallows (Vegetation type)	Soil macroaggregates can be broken into pieces, “suelo suelto”, loose soil/Macroaggregates can not be broken, “suelo amarrado”, tied soil. (Structure)	High yields/low yields. (Yields)	“Porosita”, “despolvorienta”, loose soil, “se desparrama”, non-compacted / No se desparrama, compacted. (Structure)	“Tierra se espolvorea”, soil is not compacted/ soil compacts as balls, “se amarra”, it is tied up. (Structure)
4	Good weed growth/ poor weed growth. (Type of vegetation)	“Terronosa”, aggregated, “suelta”, loose/”Masiva”, compacted. (Structure)	No burnings have occurred in the last 5 years/Lands have been burned in the last 5 years. (Soil burning)	Without “manto” or incorporating decomposing residues/ with “manto”. (Soil organic matter)	New land use<10 yrs, from pasture to crop-land, land from ancestors was good/ old land, greater than 10 years of use. (Length of current land use)	Does not occupy fertilizer/needs fertilizer. (Fertility)
5	No burning/burning. (Soil burning)	Soil with a black layer/ Soil with litter or without black layer. (Soil organic matter)	“Zaléa”, “Chichiguaste”/ “Chichiguaste” does not grow, weeds do not develop, “zacate de gallina”. (Indicator plants)	“Suelta”, loose, “suave”, soft, “terronosa”, large aggregates/”Tablones”, laminar structure. (Structure)	No burning/burning (Soil burning)	No burning/burning (Soil burning)
6		No burning/burning. (Soil burning)	Greater yields/Lower yields, more work to produce. (Yield)	No burning/burning. (Soil burning)	“Manto”, organic residues incorporated into the soil/ ”Manto” not incorporated. (Soil organic matter)	
7			Soil does not flood, no “aguachina”/ “aguachina”, “sweaty” soil. (Drainage)	“No se aguachina”, does not flood/”Se aguachina” gets muddy, water does not filter through. (Drainage)	Soil does not fill with water, “No se empapa”/soil fills with water, “Se empapa”, “pichera”. (Drainage)	
8			Non washed soils/ washed soils (Erosion)		Crops grow with little or no fertilizer/only growth with fertilizer. (Fertility)	
9					Un-washed land/ washed land. (Erosion)	

* Ranking values are inversely related to degree of importance (i.e. 1 = highest importance).

It is important to note that the type of native vegetation present in a soil is a local indicator of soil quality (Table 12) that not only cuts across the communities studied in Honduras but also across the previous case studies reported here. This observation suggests that there may be an underlying fundamental ecological principle behind farmer observations in the two locations. It is proposed here that one such ecological principle is that of natural succession. Natural and agricultural ecosystems respond similarly to degradative or regenerative processes through natural succession. The most adapted plants and organisms in the soil gradually replace less adapted ones as continued selective pressures are exerted (i.e. during regeneration of soil fertility or soil degradation). Native plants and "weeds", as biological indicators, have the potential to capture subtle changes in soil quality because of their integrative nature. They reflect simultaneous changes in physical, chemical and biological characteristics of the soil. There is considerable scope, therefore, to further explore the use of local knowledge about native plants as indicators of soil quality and as a tool guiding soil management decisions.

Table. 12 Most important plant species used as local indicators of soil quality by Tascalapa watershed hillside farmers, Honduras.

Common name	Scientific name	Botanical family	Plant type**	Soil type
Chichiguaste	*Eletheanthera ruderalis*	Asteraceae	H	Fertile
Verdolaga	*Portulaca oleraceae*	Portulacaceae	H	
Malva	*Anoda cristata*	Malvaceae	H	
Zalea	*Calea urticifolia*	Asteraceae	H	
Guama	*Inga sp.*	Fabaceae	T	
Quilete	*Phytolaca icosandra*	Phytolacaceae	H	
Pica pica	*Mucuna pruriens*	Fabaceae	H	
Zacate de gallina	*Cynodon dactylon*	Gramineae	H	Poor
Tatascán	*Perymenium nicaraguense*	Asteraceae	H	
Pino	*Pinus caribeae*	Pinaceae	T	

** Plant type: H = herbaceous, T = tree.

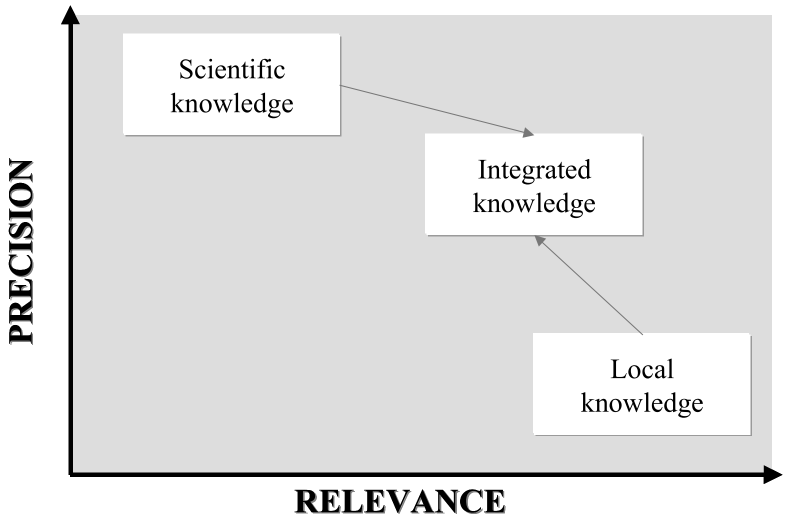

Figure 7 Integration of local and scientific knowledge systems

Implications for ISFM across the landscape: Farmers are often more enthusiastic to empirical approaches (i.e. local knowledge, on-farm experiments) than prescriptive approaches (i.e. scientific knowledge, recipes for soil management). Figure 7 illustrates that while scientific information can be very precise its relevance can be relatively low. On the other hand, while local information can be relatively imprecise, yet, it can be very relevant. Although information should ideally be certain in both meaning and context, in reality this is not the case. Research efforts should further explore a suitable balance between precision and relevance as seen in the figure.

Impacts:
The considerable importance of local knowledge in guiding future research and development efforts towards a sustainable management of natural resources is highlighted in this study. The case studies presented showed that there is a consistent rational basis to the use of local indicators of soil quality. The use of key-informants was effective to elicit local information about soils and their management. Participatory approaches involving group dynamics and consensus building, however, are likely to be key to integrated soil fertility management beyond the farm-plot scale to the landscape scale through the required collective action process.

Native plants were important local indicators of soil quality in all three case studies associated with modifiable soil properties. The use of indicator plants, belonging to the local knowledge base, when related to management actions could ease adoption of improved technologies. This approach would allow the use of plants as indicators of soil quality to which local farmers can relate more closely than to common agronomic measures like available phosphorus or pH value. Additional research could also include further integration of scientific spatial analysis (i.e. GIS, topographic modeling) with the spatial perception of natural resources by farmers aiming at improved implementation of site-specific management.

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1.4 Characterize plant components for production potential, nutrient use efficiency (phosphorus and nitrogen) and improvement of soil physical conditions

1.4.1 Use of deep rooted tropical pasture components to improve soil physical conditions

Highlight:

- Showed that deep-rooted tropical pastures can enhance soil quality by improving the size and stability of soil aggregates when compared with soils under monocropping.

Purpose:
To determine the usefulness of deep rooted tropical pasture components to improve soil physical conditions.

Rationale:
Agricultural sustainability implies that agriculture will remain the principal land use over long periods of time relative to human life-span and it is economically competitive and ecologically acceptable while the soil resource base maintains or even improves its fertility and health. One of the major challenges for the achievement of sustainable agriculture in the tropics, is the vulnerability of tropical soils to degradation when they are subjected to mechanization for crop production. It is widely believed that tropical savanna soils (mainly Oxisols) have excellent physical characteristics such as high infiltration rates, high permeability, good and stable soil structure and therefore can support mechanized agriculture. However, recent work indicated that Colombian savanna soils (Oxisols of Altillanura), have serious physical, chemical and biological constraints for crop and pasture production. Physically the fertile layer can be shallow with high bulk densities together with weak structure. Tillage (disc harrowing) practices currently used for seedbed preparation could result in surface sealing and low rainfall acceptance capacity. Chemically the soils have low pH values, high levels of exchangeable Al^{+3}, low P availability, low base (Ca, Mg and K) saturation and low amounts of organic matter. Also, biologically they show constraints typical of soils with low organic matter such as lower rates of mineralization.

Physical, chemical and biological conditions of these soils need to be improved in order to increase their productivity. Usually this improvement can be achieved by land preparation and by application of lime and fertilizer. However, this effect lasts only for a short time and after 4 to 7 years, farmers abandon the degraded land as it is no longer productive and often migrate to other areas. To avoid the continued degradation of these soils and to achieve sustained production, we propose that the construction of an "arable layer", a top layer with improved soil properties, is required.

It has been demonstrated that soil physical conditions are usually best under permanent grassland (or forest) and as soil is cultivated, these conditions deteriorate at a rate dependent of climate, soil texture and management. We have found significant negative effects of continued cropping on the physical properties of soils in the Llanos. Studies from the Casanare region of the Llanos showed that total porosity and macroporosity decrease markedly after 5-7 years of monocropping.

The purpose of this study was to evaluate the influence of deep-rooted tropical pastures in comparison with other land uses such as monocropping of upland rice and native savanna pastures on the improvement of soil properties.

Materials and Methods:
Location: The experiments were carried out at Matazul farm (4º 9′ 4.9″ N, 72º 38′ 23″ W and 260 m.a.s.l.) located in the Eastern Plains (Llanos) near Puerto Lopez, Colombia. Prior to treatment application, the area was under a native savanna pasture consisting of native grasses. The soil has low fertility and the

availability of P in the soil is low because of the soil's high P fixation capacity. The soil is classified as Isohyperthermic Kaolinitic Typic Haplustox in the USDA soil classification system.

Treatments: To evaluate the impact of deep-rooted pastures on soil physical characteristics, we used the following treatments from long-term experiments:

a) Aggregate size distribution and aggregate stability aspects were studied in an experiment where disturbed and undisturbed introduced pasture systems were compared with rice monocropping on two sites of contrasting soil texture (Matazul: clay loam; Primavera: sandy loam). Native savanna (undisturbed) system was used as a control. Disturbed pasture received two harrow passes for every two years to reduce surface sealing and compaction.
b) Infiltration rates were measured in an experiment aimed to improve top soil conditions (cultural profile) using different intensities (1, 2 or 3) of chisel passes (vertical tillage) or different agropastoral treatments (pasture alone, pasture+legume and legumes alone) that were planted after 2 passes of chisel.
c) Measurements on volume and chemical composition of gravitational water were studied in an experiment aimed to understand the processes of soil degradation due to either monocropping of rice or introduced pasture (*Brachiaria dictyoneura* cv. Llanero). Different number of harrow passes (2, 4, 8) were applied every year for a period of two years for each treatment.
d) Root biomass and root volume of *Brachiaria decumbens* were determined in two contrasting textural soils: sandy-loam and clay-loam, under two pasture conditions: productive and degraded (less productive), to compare root growth under these two conditions.

Evaluated Parameters:
Aggregate size distribution and aggregate stability: Ten volumetric soil samples were taken in cylinders (120 mm diameter by 25 mm high) and used for dry aggregate size distribution determinations from each of the following treatments: disturbed pasture, undisturbed pasture, monocrop and native savanna. Disturbed pasture means that two harrowing passes were made every 2 years to loosen the soil to improve pasture productivity. By the time of the evaluation, the experimental plots had 8 years of establishment. In each of the 10 samples taken from each treatment, a test for dry aggregate size distribution was made using the total volume of soil collected in the cylinders. Sieves of the following openings were used: >6, 6-4, 4-2, 2-1, 1-0.5 mm, which were fitted to a shaker.

Aggregate stability was determined also using 10 samples (50 g of soil) for each treatment with a Yoder apparatus (Angers and Mehuys, 1993). A set of sieves with openings of: 2, 2-1, 1-0.5, 05-0.25, 0.25-0.125 and <0.125 mm was used. The amount of sand found in each sieve was discounted from the total weight.

Infiltration rate: A double ring devise was used to determine infiltration rates. Five tests for each treatment were made. Internal cylinder was inserted into the soil to 5-7 cm soil depth. External cylinder was inserted to 3-5 cm. Water was poured first to the external cylinder and then to the internal. The amount of water entering into the soil was measured at different time intervals during a testing period of two to three hours, until a quasi equilibrium of amount of water entering in function of time was reached.

Collection of gravitational water: It is not common to collect and measure the amount and elemental composition of free water (drainage water) from the precipitation that moves down in a soil profile at different depths. In this study we determined the influence of pastures or monocropping of upland rice on the amount of gravitational water and its elemental composition at different soil depths. A pit of 1.8 m length × 0.7 m wide × 0.5 m depth m was dug in each treatment. Funnels filled with clean fine and very fine sand, were wetted to field capacity and then buried in the soil profile at different depths: 3, 5, 10, 15 and 30 cm to collect the gravitational water that passes through each depth, during part of the rainy season. Measurements of the amount of water and elemental composition, were made at different times. During the period of measurements, the pits were protected around and covered with a sheet of zinc to avoid any other water entering into the pit. This methodology assumes that there is a vertical piston like water movement. The accepted rain moves through the soil profile and the extent of the funnel diameter represents a funnel from the depth at which the cylinder is buried to the top of the soil. Wet sand in the funnel is required to obtain pore continuity in the drainage process.

Root distribution: Root sampling was carried out using trench profile method. Three sampling points were randomly located within each treatment of degraded or productive pasture of *Brachiaria decumbens*. A trench of 60 cm wide, 50 cm deep and 60 cm long was dug to determine root penetration and root distribution. Root samples were excavated from the wall of each trench, from each treatment. The nail-boards were made of a 2 cm thick plywood board (50 cm wide and 40 cm long). Twelve cm long nails were inserted at 10 cm intervals (10 x 10 cm) through the back of the board and protruded into the frame 10 cm. Root samples were collected by pressing the nail-boards into the trench wall and slicing the enclosed soil monolith from the trench wall with a steel blade. The samples were soaked in water for at least 2 h after which the soil was removed from the roots with a fine spray of water. The root samples were photographed. Root volume was determined with a measuring jar filled with water by registering the increase in volume. Root biomass (dry weight) was recorded after oven drying for 2 days at 65°C.

Results and Discussion:
Aggregate size distribution and stability: Effect of different management systems. The aggregate size distribution under different management systems is shown in Table 12. At Matazul Farm, the percentage of aggregates >6 mm, 6–4 mm and 4–2 mm decreased in intervened systems compared with the native savanna, while those between 2–1 mm, 1–0.125 mm and <0.125 mm increased. This was noted particularly under monocropped rice. At La Primavera Farm, monocropping with rice resuted in a lower percentage of 4–2 mm and higher percentage of 2–1 mm and 1.0–0.125 mm aggregates. In contrast, the undisturbed pasture had a positive effect on soil aggregation, with the highest (non-significant) percentage of aggregates larger than 2 mm.

To better characterize the influence of soil management on aggregate size, the medium diameter (D_{50}) was calculated. In the case of Matazul, the equivalent D_{50} diameter for native savanna was 1.90 mm whereas for rice monocrop it was 0.4 mm. Disturbed and undisturbed pastures had values of 0.85 and 1.35 mm, respectively. The situation differed somewhat at La Primavera: native savanna exhibited a D_{50} value of 1.50 mm while the undisturbed *Brachiaria* pasture gave a D_{50} value of 1.80 mm, showing the influence of the pasture on soil aggregation.

The results on aggregate stability are presented in Table 13. Aggregate stability values at Matazul Farm were greater for native savanna than for intervened systems. The percentage of stable aggregates larger than 2 mm was significantly greater in relation to other treatments. At La Primavera Farm, undisturbed pasture and native savanna both had a higher percentage of aggregates larger than 2 mm diameter.

Infiltration rate: Infiltration rates, determined under different management system treatments in an experiment aimed to create an arable layer, are shown in Table 14. In relation to native savanna the treatments that included introduced pastures showed higher and more stable rates. Particularly higher rates of infiltration were found under *A. gayanus* pasture.

Gravitational water: The amount of gravitational water draining at different soil depths as a function of soil management system is shown in Table 15. Little water was collected in the top layers of soil of savanna while greater amounts were collected at 15 cm soil depth. The treatment sown to upland rice with 8 harrow passes, did not allow the movement of free water through the soil. With 16 harrow passes more water was able to enter into the soil especially in the top two layers. Under introduced pasture, the amount of free water entering and moving through the soil profile was extremely high (480 cm^3 with pasture vs 0 cm^3 with monocropped rice for 8 harrow passes and 490 cm^3 with pasture vs 100 cm^3 with monocropped rice for 16 harrow passes) at 3 cm of soil depth (Table 15).

The chemical composition of the water collected at different soil depths under upland rice and pastures is shown in Table 16. Higher amounts of nutrients, especially at the first two depths were found under rice.

Root distribution: Examination of soil monoliths collected through profile wall technique showed marked differences in root penetration and root distribution between a degraded pasture and a productive pasture of *Brachiaria decumbens* (Figure 8). Differences in root biomass and root volume at different soil depths, as influenced by soil texture (clay-loam and sandy-loam) are shown in Table 17. Clearly the productive pasture shows a better and abundant root systems than the degraded one.

Table 12. Aggregate size distribution (%) as influenced by soil management system in savanna soils of Colombia.

	% of aggregates of size (mm)*					
Treatment	>6	6-4	4-2	2-1	1-0.125	<0.125
Matazul Farm						
Undisturbed pasture	14 b	11 b	16 a	15 b	32 b	12 ab
Disturbed pasture	21 a	11 b	15 ab	15 b	27 c	11 b
Rice monocropping	7 c	7 c	13 b	17 a	44 a	13 a
Native savanna	22 a	14 a	16 a	11 c	24 c	10 b
La Primavera Farm						
Undisturbed pasture	14 a	15 a	26 a	17 b	22 b	5 b
Disturbed pasture	6 b	7 c	17 ab	22 a	37 a	11 a
Rice monocropping	13 a	12 b	15 b	18 b	31 a	10 a
Native savanna	11 a	11 b	26 a	18 b	24 b	9 ab

** Values within an aggregate size class and farm followed by the same letter are not significantly different at $p<0.05$.*

Good soil management should aim to create optimum physical conditions for plant growth. These include: a) adequate aeration for roots and microorganisms. b) adequate available water, c) easy root penetration, d) rapid and uniform seed germination, and e) resistance of the soil to slaking, surface sealing and accelerated erosion. Results from this study indicate that change in land use as deep-rooted tropical pasture can enhance soil quality by improving the size distribution of stable aggregates when compared with soils under continuous upland rice monocropping. The greater percentage of stable aggregates with introduced pastures compared with monocropping indicates that any kind of soil disturbance negatively affects aggregate stability, possibly through its influence on soil organic matter or some of its components. Compared with native savanna, introduced pastures also showed higher and more stable rates of water infiltration, particularly with *A. gayanus* pasture. These results reconfirm the benefits of introduced pastures in improving soil quality.

The improvement of the structural condition of soils by pastures, when they are used for grazing, normally change to less beneficial values of porosity, infiltrability, etc., as a consequence of trampling. However, strategies to maintain a good soil structural quality can be developed with proper grazing management.

Table 13. Percentage of stable aggregates under different management systems on a Colombian savanna Oxisol.

	% of stable aggregates of size (mm)*					
Treatment	>2	2-1	1-0.5	0.5-0.25	0.25-0.125	<0.125
Matazul Farm						
Undisturbed pasture	75 c	7.2 a	4.0 a	1.6 a	1.6 a	10.0 ab
Disturbed pasture	79 bc	4.5 b	2.7 b	1.2 b	0.9 ab	11.4 a
Rice monocropping	84 b	3.6 b	2.6 b	1.2 b	0.9 ab	7.8 ab
Native savanna	93 a	1.2 c	0.6 c	0.3 c	0.3 b	4.2 b
La Primavera Farm						
Undisturbed pasture	94 a	1.0 c	0.5 c	0.5 b	0.2 b	3.7 b
Disturbed pasture	78 c	7.6 a	3.7 a	1.3 a	1.2 a	8.7 a
Rice monocropping	84 b	4.4 b	2.3 b	0.8 ab	1.0 a	7.8 a
Native savanna	93 a	1.7 c	0.6 c	0.3 b	0.2 b	4.4 b

** Values followed by the same letter are not significantly different at $p<0.05$.*

Table 14. Rate of water infiltration (cm. h^{-1}) as influenced by different treatments in the experiment on building an arable layer (Matazul Farm).

	Infiltration rate (cm h^{-1})	
Treatment	1998	1999
Rice-soybean rotation		
1 chisel pass	2.0 c	5.5 bc
2 chisel passes	1.6 c	7.4 bc
3 chisel passes	2.2 c	7.5 bc
Rice + Pastures		
a) Early incorporation of residues		
A.gayanus (Ag)	17.0 a	15.0 a
Ag+legumes (Kudzu+*ovalifolium*)	8.8 abc	5.6 bc
Legumes (Kudzu+*ovalifolium*)	9.7 abc	6.8 bc
b) Late incorporation of residues		
A.gayanus (Ag)	8.5 abc	9.4 b
Ag+legumes (Kudzu+*ovalifolium*)	6.5 bc	5.2 bc
Legumes (Kudzu+*ovalifolium*)	14.2 ab	3.1 c
Native savanna (control)	1.7 c	3.7 bc
Significance level	0.07	0.006

** Values followed by the same letter are not significantly different at $p<0.05$.*

Table 15. Gravitational water collected (ml) at different soil depths for different systems of soil management (Matazul Farm).

Depth (cm)	Amount of water collected (ml)				
		Rice		Pasture	
	Native savanna	8 harrow passes	16 harrow passes	8 harrow passes	16 harrow passes
3	3	0	100	480	490
5	2	0	136	480	490
10	4	1	0	480	447
15	490	2	0	440	132
20	1	0	0	40	78
30	0	3	0	0	460

Table 16. Elemental composition of gravitational water collected at different depths and management systems (Matazul Farm).

Crop	Depth (cm)	mg L^{-1}					Electrical conductivity ($\mu S/cm^{-1}$)	pH
		N	K	Ca	Mg	Al		
Rice	3	8.5	12.0	2.9	0.5	6.0	103.8	5.8
	5	2.8	10.4	6.0	1.0	17.5	90.0	6.0
	3	1.7	4.1	1.7	0.5	2.2	463.0	5.9
	5	2.9	0.6	1.6	0.3	1.4	29.5	6.2
Pastures	10	2.0	1.4	0.8	0.2	0.4	288.0	6.1
	15	2.0	2.6	2.8	0.4	0.6	47.5	6.6
	20	2.7	1.5	2.3	0.4	0.5	56.3	6.7
	30	4.8	3.8	3.7	1.0	1.7	79.0	6.6

Table 17. Root biomass (g) and root volume (cm^3) of *Brachiaria decumbens* at different soil depths as influenced by level of pasture productivity (degraded or productive) on two soil types.

Soil depth (cm)	Sandy-loam			Clay-loam		
	Degraded	Productive	$LSD_{0.05}$	Degraded	Productive	$LSD_{0.05}$
Root biomass (g)						
0-15	0.7	1.3	0.64	1.0	1.7	NS
15-25	0.2	0.2	NS	0.3	0.3	NS
25-40	0.1	0.3	0.08	0.2	0.2	NS
Root volume (cm^3)						
0-5	6.5	9.7	NS	8.5	15.7	5.6
15-25	2.2	2.7	NS	2.7	2.6	NS
25-40	1.2	2.7	0.8	2.1	2.1	NS

Degraded **Productive**

Figure 8. Root distribution under degraded and productive *Brachiaria decumbens* pasture.

Little amount of gravitational water was collected in the top layers of soil of native savanna while greater amounts were collected at 15 cm soil depth suggesting the existence of preferential flow. This could be due to the wetting mechanisms dominant in the natural savannas. The treatment sown to upland rice with 8 harrow passes, did not allow the movement of free water through the soil, probably as a result of surface sealing that impeded the entrance of water. Under 16 harrow passes more water was able to enter into the soil especially in the first two depths, showing that there was a better rainfall acceptance under this treatment. The greater amounts of gravitational water entering and moving through the soil profile of introduced pasture in comparison with monocropping of upland rice indicates that introduced pastures are a very good alternative to improve and maintain the amount of macropores (pores that permit the free movement of water). This result confirms the beneficial effects of agropastoral system for improvement of these soils. Results on the chemical composition of the gravitational water collected indicate the beneficial effects of introduced pastures both on water and nutrient redistribution in the top soil layers. However, it is important to note that pastures were sown a year before rice.

Four aspects of the research deserve attention: a) The methodology used was appropriate as it was possible to collect drainage water and differentiate between treatments, b) there is a very high variability in the way the water moves into the soil (preferential flow), c) the amount of nutrients that move from one depth to other is a function of the amount of water draining, and d) the capacity of the pastures to allow a better water and nutrient distribution should be used to improve soils.

Impact:
This study shows that introduced pasture components can enhance soil quality by improving the size distribution of stable aggregates, infiltration rates and rainfall acceptance capacity when compared with soils under monocropping. Use of introduced pastures with deep rooting abilities can result in increased soil organic matter and associated improvements in soil physical and chemical properties.

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Activity 1.5. Determine rooting strategies of crop, forage and improved fallow components

1.5.1 Developing methods to determine root distribution and abundance of two improved fallow species in stony Nicaraguan soils

Highlight:

- Developed methodology to determine root distribution and abundance for stony soils predominant at Nicaraguan reference site.

Purpose:
To determine the root distribution and abundance of *Sesbania sesban* and *Tephrosia* spp. growing in two different soil conditions

Rationale:
Improved fallow systems provide a faster regeneration of soil fertility than the natural regeneration by the native flora. The improvement of fallows is an addecuate technological entry point because it is of low risk for the farmer, is of relatively low cost and can have the incentive of generating additional products besides soil fertility improvement (i.e. fuelwood). A very important component of soil fertility regeneration is related to the capacity of improved fallow species to add considerable amounts of organic inputs aboveground through litterfall and prunnings as well belowground through root development and turnover during and after the fallow period. Thus, root turnover can increase the organic matter levels in the soil, even when the above ground biomass is removed. Therefore, understanding their role in soil fertility regeneration is essential.

The capacity of few improved fallow tree/shrub species tested in SOL-Wibuse (San Dionisio, Nicaragua) to develop well in stony soils was attributed to their rooting strategies by local farmers. This study aimed at identifying rooting patterns of the two best adapted improved fallow species in our adaptation trials: *Sesbania sesban* and *Tephrosia* spp. We used a modified versión of the methodology described in Anderson and Ingram (1993) as shown below.

Materials and Methods:
Treatments description: Root studies were conducted in an adaptation trial for potential fallow species at the SOL-Wibuse in San Dionisio, Nicaragua. In this trial, 5 legume species (Table 18) were planted in two different sites: site 1 has few stones and light slope, while site 2 has more stones and higher slopes.

Table 18. Species tested in adaptation trial experiments in Nicaragua (SI = soil improvement, F = Fodder, W = Wood, FW = Firewood, Fo = Food, LF = Live fence, M= Medicinal use, I = Insecticide)

	Reported uses							
Specie	SI	F	W	FW	Fo	LF	M	I
Flemingia macrophyla	X	X		X		X		
Tephrosia candida	X						X	X
Tephrosia vogelii	X						X	X
Sesbania sesban	X	X		X	X		X	
Rhynchosia schombergii	X	X						

Only the two best adapted species to both sites were selected for this study: *Sesbania sesban* and *Tephrosia* spp. The trees were planted in June of 2000 at 1.5 m spacing in a staggered arragement in adaptation plots. Root studies were conducted 1 year after planting (June – July of 2001).

Root mapping: The root map has the purpose to allow the estimation of the total root density throughout the soil profile, and was carried out as follows: A pit (0.75 m width, 3-4 m length and 0.7 m minimum depth) was initially prepared on one side of each plot, 50 cm apart from the most outward line of trees. Carefully, the pit wall closer to the trees was cleaned and straightened with shovels, blades and knives. Stones were removed from the wall when they were not very deep; otherwise, they were left intact. Weed roots were removed to prevent their inclusion in the map. Tree roots exposure was facilitated by applying water with a sprayer and brushing the soil wall with a plastic brush. Next, the profile wall was covered with a translucid PVC sheet, where horizontal and vertical lines had been drawn to generate a grid pattern (10 x 10 cm), to record rotos, stones, and different soil horizons (Figure 9). Each root was marked with a dot, trying to simulate the thickness of the roots. The roots were only recorded if they (or their projections) intercepted the PVC sheet.

After mapping in the field, maps were transferred to grid paper at scale (10:1). Root abundance (number of dots by area) could be estimated as a function of distance of the trees. The number of dots (roots) by horizons indicates the root abundance as affected by soil depth.

Map calibration: To obtain quantitative results it is necessary to calibrate the maps. Therefore, for each 10 cm soil depth a small block of soil (10 cm length x 20 cm width x 2.54 cm depth) was taken from the pit wall mapped, packed in a polyethylene bag and brought to the laboratory.

Next, soil from each block was washed with water over a set of two mesh sieves (0.3 mm + 0.2 mm) and a plastic bucket to carefully collect the roots present. Extracted roots were placed over a glass plate containing water, cleaned (to remove debris) and stored. Only living roots from the sampled trees were kept. Following sorting and washing, water was removed and roots were randomly oriented on the plate, and the one grided acetate (1 x 1 cm) was placed over the plate.

Counts of root intersections (N) with the vertical (V) and horizontal (H) lines of the grid (acetate) were recorded and added ($N = V + H$). Root length (L) is obtained by the formula: $L = \pi N D / 4$, where D is the grid size in mm. (10 mm) (Figure 11).

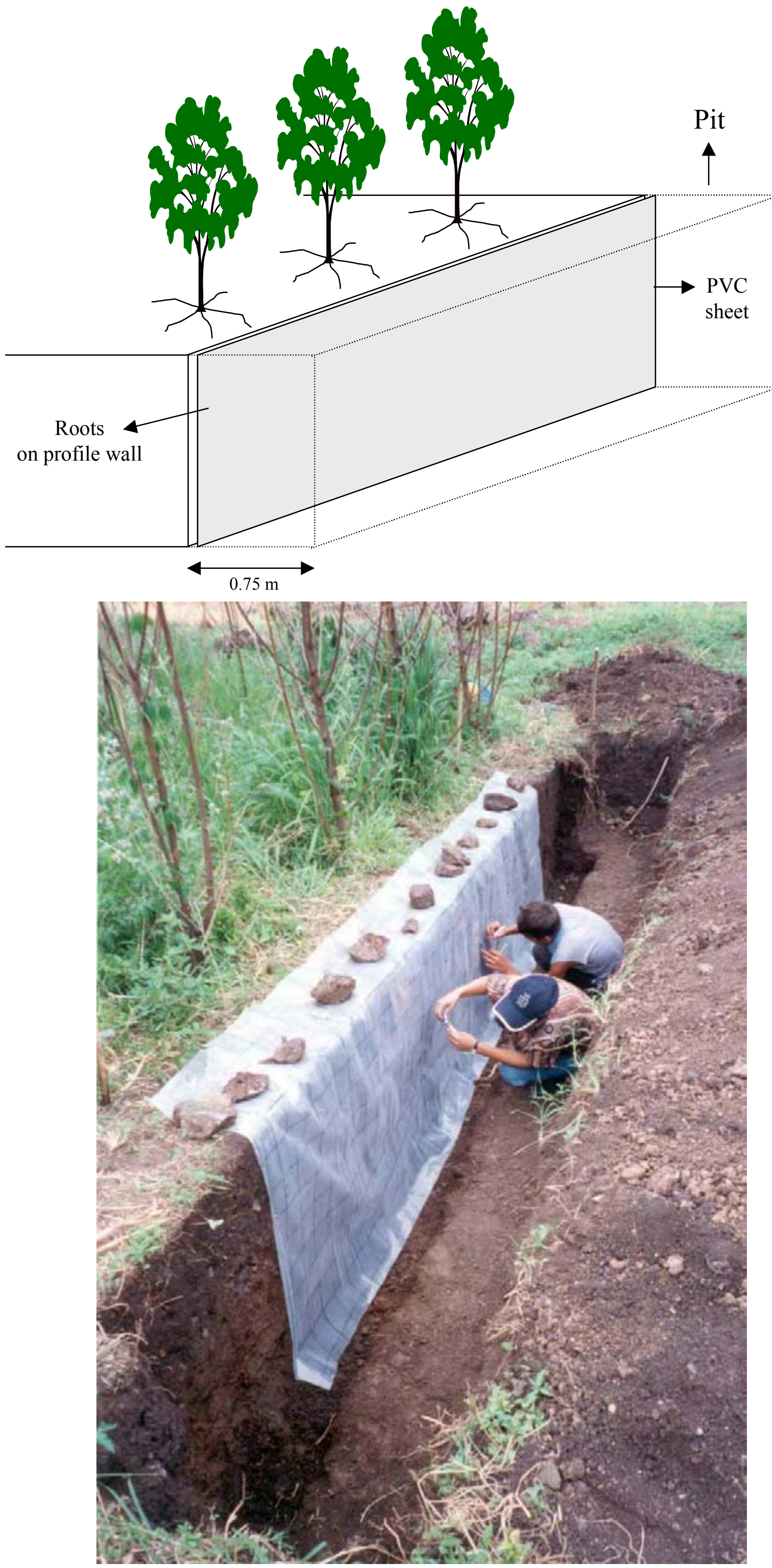

Figure 9. Root mapping: details about preparation of pits and location of PVC sheets on pit wall.

For *Sesbania*, in zone 1, two trees were selected for mapping (3 m length map), while three trees were sampled in zone 2 (4.5 m length map) (Figure 10). However, and because a higher mortality of *Tephrosia* spp., only one tree of this species was selected for zone 1 (1.5 m length map) and two trees for zone 2.

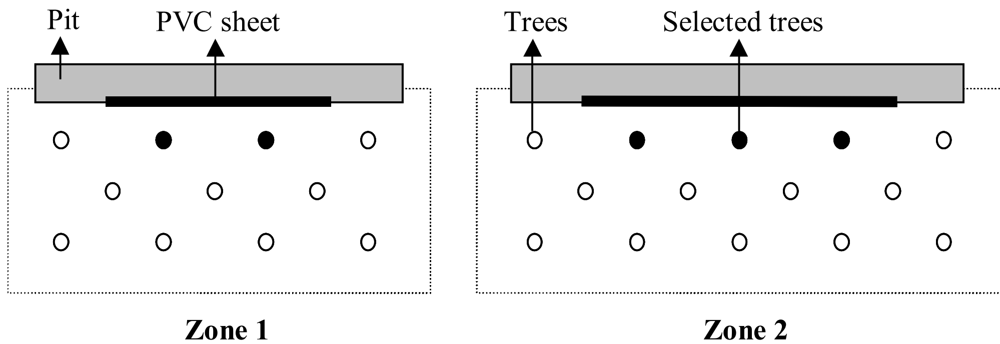

Figure 10. Selected trees for sampling in both zone 1 and zone 2 (example for *Sesbania*).

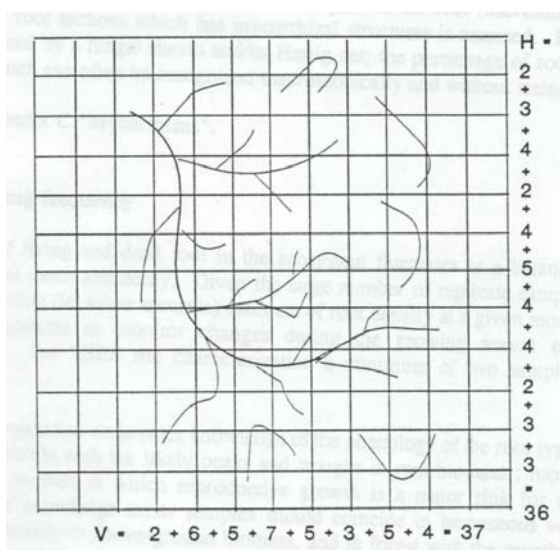

Figure 11. Linear interception method used to determine the root length.

Root pattern graphics: Root pattern graphics have the purpose to capture graphically the root distribution observed in the carefully prepared wall of the soil pit. This activity followed the root mapping, and the methodology used is described as follows:

In the same pit wall used for root mapping, soil was carefully removed from the pit wall all the way to the base of the trees under study (50 cm inside the pit), taking care that root systems of selected trees are not damaged (Figure 12). This work was performed manually with small pointed woody stakes and blades.

During this process, water was frequently applied with a sprayer over the roots to prevent their desiccation. Additionally, each tree was tied with cords to soil to avoid that strong winds could knock it down.

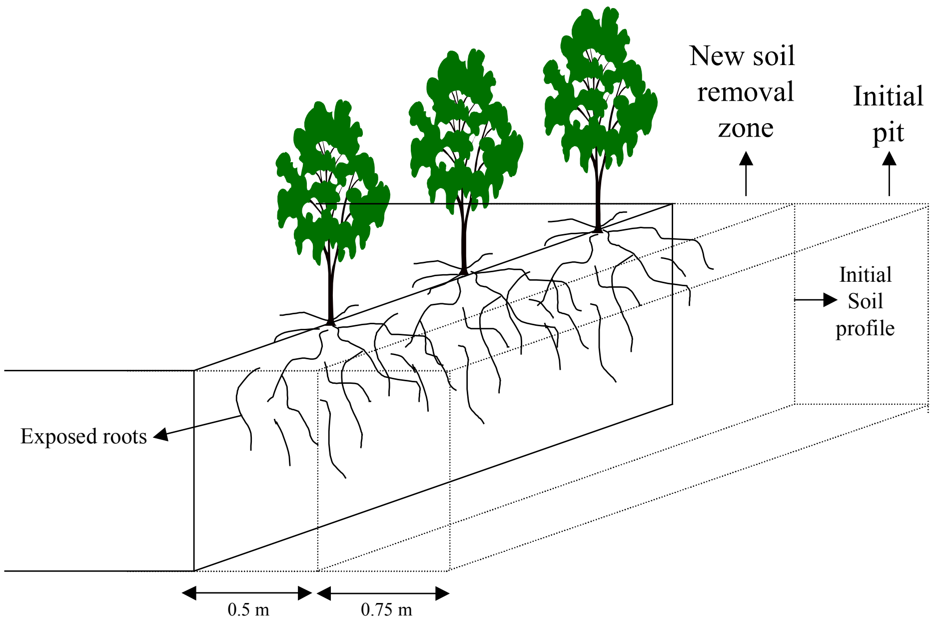

Figure 12. Soil removal to expose the root system of trees.

Next, a grid over the new wall was constructed (in the base of the trees) to help in drawing of root maps. The methodology used is shown in Figure 13.

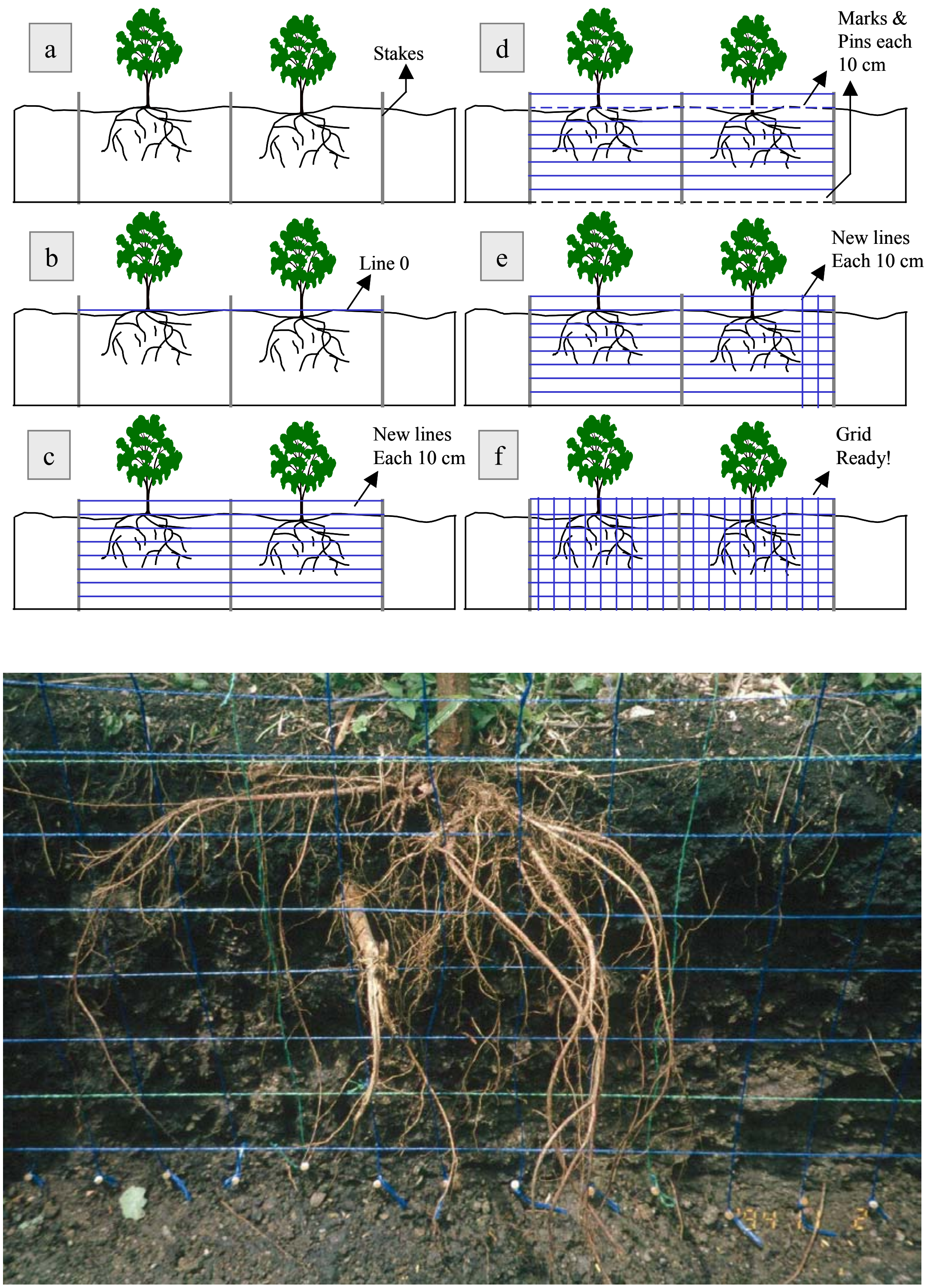

Figure 13. Making the grid (steps) to help the drawing of root graphs.

After making the grid, the roots were drawn in a grid paper at scale of 10:1. In the graph, stones present were also drawn.

Results and discusión:

Root mapping: In Figure 14, root maps of *S. sesban* (SES) and *Tephrosia* spp. (TEP) (zone 1) are shown. Some initial qualitative observations can be made: *Sesbania* presented higher number of dots (roots) than *Tephrosia.* Additionally, we can observe that sites differed in the abundance (> *Sesbania*) and size of stones (> *Tephrosia*) present as well as in the depth of soil horizons present.

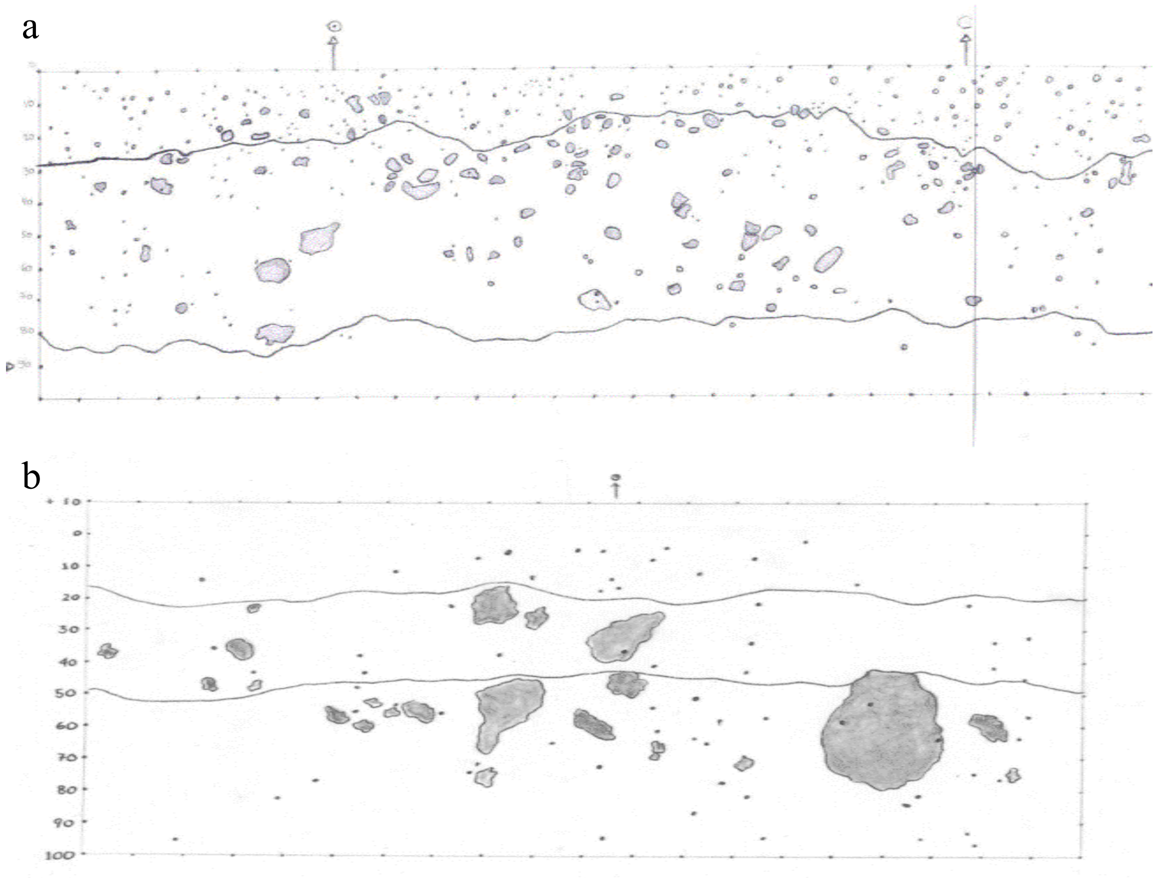

Figure 14. Root maps for two trees of *S. sesban* (a) and one of *Tephrosia* spp. (b) in zone 1. Dots are the roots and stones are the darker semicircles. Marks over the map indicate location of tree(s) and continuous horizontal lines drawn represent the three soil horizons found.

The information provided by root maps allows the calculation of root density (number of roots by unit area). Root counts (Table 19) supports the initial observations in the map showing that *Sesbania* had higher root density than *Tephrosia* in whole profile. The root density decreased with soil depth, for both treatments, being generally higher in the first 20 cm.

Likewise, we can observe that tree root density decreased with distance from the tree base, being higher in the first 35 cm (Table 20), with *S. sesban* maintaining higher root counts than *Tephrosia* spp.

Table 19. Variation of tree root density (number of roots *per* cm^2) of *Sesbania sesban* (SES) and *Tephrosia* spp. (TEP) with depth.

	Depth (cm)									
Treatment	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
SES*	0.45	0.47	0.31	0.19	0.06	0.12	0.08	0.09	0.04	0.00
TEP	0.07	0.08	0.03	0.04	0.05	0.09	0.05	0.06	0.05	0.05

* Mean of two trees sampled.

Table 20. Variation of root density (number of roots *per* cm^2) for *S. sesban* and *Tephrosia* spp.with the distance from the tree base.

	Distance from the base of selected trees (cm)							
Treatment	0-5	5-15	15-25	25-35	35-45	45-55	55-65	65-75
SES*	0.18	0.12	0.11	0.16	0.11	0.12	0.13	0.10
TEP	0.07	0.04	0.05	0.06	0.02	0.03	0.01	0.03

* Mean of two trees sampled.

Map calibration: Table 21 shows the results obtained for the calibration of the root maps prepared for *S. sesban* and *Tephrosia* spp. The calibration corroborated that *Sesbania* presented higher abundance of roots than *Tephrosia* spp. and showed that root length decreased with depth, showing maximum values at 0-20 cm depth.

Table 21. Root length determination per unit volume of soil (cm^3) by the linear interception methodology for *S. sesban* (SES) and *Tephrosia* spp. (TEP). Root length (L) is give up by the formula: $L = \pi N D / 4$, where D is the grid size in mm (= 10)

Depth (cm)	Vertical Counts (V)		Horizontal Counts (H)		Total (N)		Root length in mm (L)	
	SES	TEP	SES	TEP	SES	TEP	SES	TEP
0-10	343	56	287	64	630	120	4948.0	942.5
10-20	246	42	319	44	565	86	4437.5	675.4
20-30	111	71	117	74	228	145	1790.7	1138.8
30-40	72	47	55	31	127	78	997.5	612.6
40-50	69	26	80	28	149	54	1170.2	424.1
50-60	78	26	86	24	164	50	1288.1	392.7
60-70	20	21	15	23	35	44	274.9	345.6

Root pattern graphics: In Figure 15 the root pattern graphic for *S. Sesban* and *Tephrosia* spp. (zone 1) is shown. Graphics illustrated details about root distribution and architecture down the soil profile and highlight the abundance of roots in *Sesbania*.

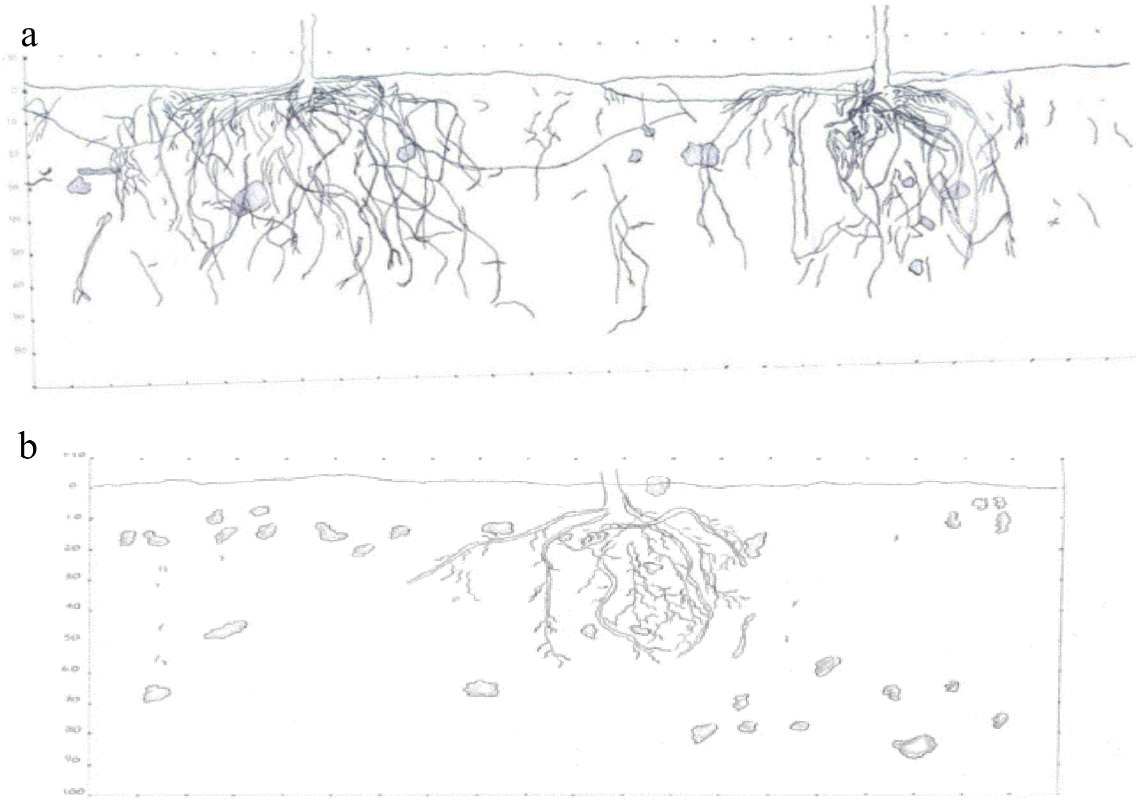

Figure 15. Root pattern graphics for *S. sesban* (a) and *Tephosia* spp. (b) in zone 1.

Impact:
Results indicate that *S.sesban* is a promising improved fallow species for the San Dionisio reference area provided its fast growing nature reaching about 3.5 m after one year producing a considerable root biomass and thus a good candidate for improved fallow agroforestry systems.

References:
Anderson J M and Ingram J S I 1993 Tropical Soil Biology and Fertility: a Handbook of Methods. 2nd. Edition. CAB International, Wallingford, Oxon, UK. 221 p.

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1.5.2 Determine the influence of no-till systems on rooting depth and grain yield of maize

Highlights:

- Showed that rooting depth and grain yield of maize could be markedly improved by direct drilling rather than chisel + direct drilling on plots planted from phase I of Culticore.

Purpose:

To determine the impact of direct drilling or chisel + direct drilling on rooting depth and grain yield of maize.

***Rationale*:**

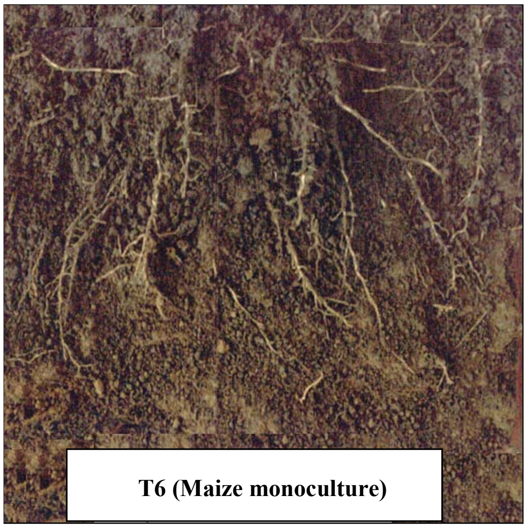
The intensification of the agricultural production in acids soils is possible through improved soil conditions in terms of fertility, structure and biological activity. Culticore (phase I) had the objective to improve the soil physical, chemical and biological conditions using different agropastoral systems. Results from phase I indicated that soil conditions were considerably improved with agropastoral systems when compared with monocropping. These improved soil conditions will permit the use of no-till systems to minimize soil degradation and sustain crop yields. Rooting strategies of crop and forage components could have important effects on nutrient acquisition, plant growth and grain yield as well as improving soil quality. As part of Culticore phase II, the present study was undertaken to determine the impact of direct drilling or chisel + direct drilling on rooting depth and grain yield of maize planted on different treatments of Culticore phase I.

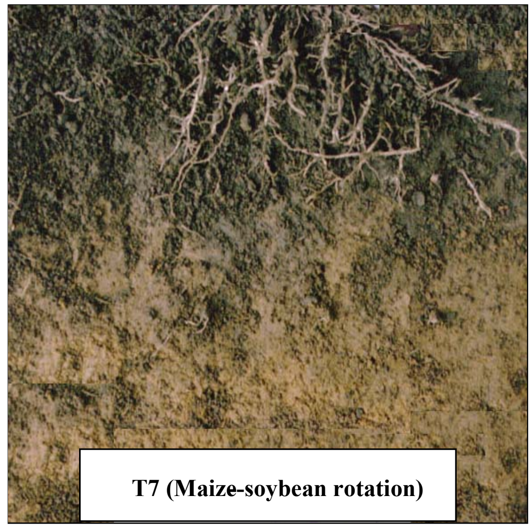
Materials and Methods:

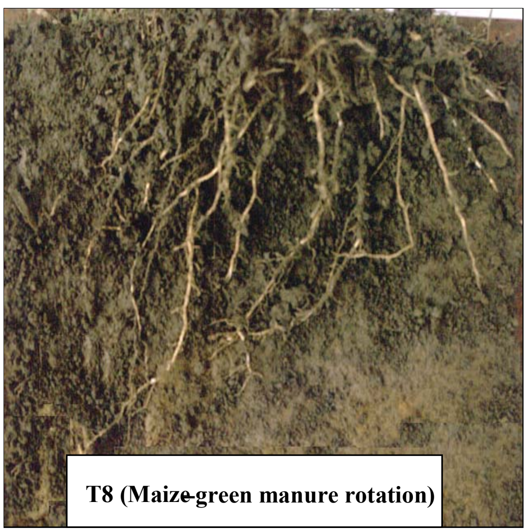
The effect of direct drilling or chisel + direct drilling on grain yields and rooting depth of maize was determined on plots from different treatments of Culticore phase I. Native savanna plots were used for baseline comparison. Rooting depth is defined as the depth of soil where the tip of the longest root is found in the soil profile. Grain yields of maize were measured at harvest.

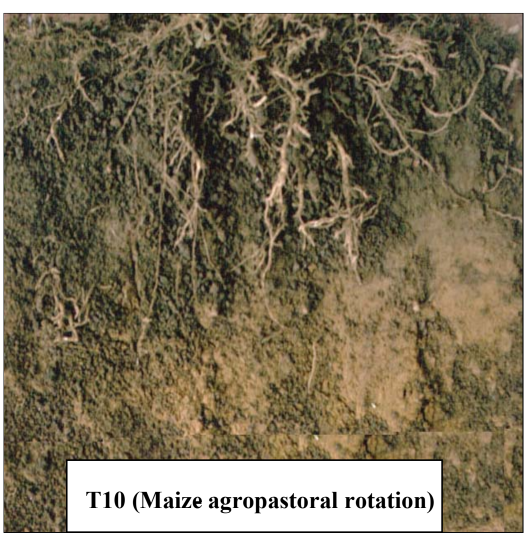
Results and Discussion:

Direct drilling treatment improved maize grain yield on plots from all treatments of Culticore phase I when compared with chisel + direct drilling (Table 22). Values on mean grain yields indicate that grain yields were greater on plots from maize-based systems than from rice-based systems. Yield on plots from Native savanna were markedly lower than that of the introduced systems. The greater yields of 4.71 and 4.24 t ha^{-1} were observed with direct drilling on plots from maize + soybean (green manure) rotation and grass + legumes pasture, respectively of maize-based systems of phase I. This superior performance of maize on these plots with direct drilling was closely related ($r^2 = 0.70$) with rooting depth of maize (Table 22; Figure 16).

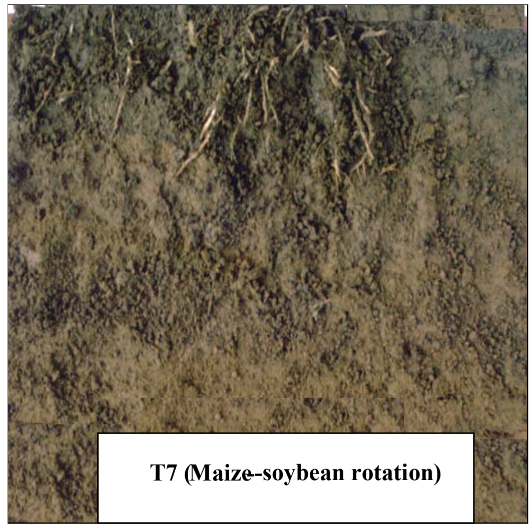


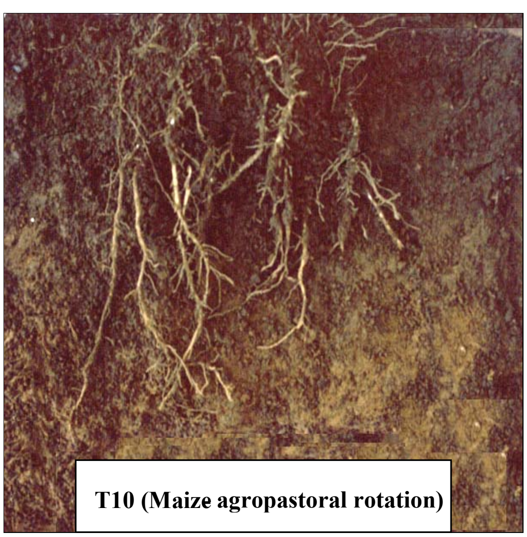






Picture 1. Influence of direct drilling on rooting depth of maize planted on different treatments of phase I of Culticore.





Picture 2. Influence of chisel + direct drilling on rooting depth of maize planted on different treatments of phase I of Culticore.

Examination of soil monoliths showed marked differences in root penetration (Pictures 1 and 2) Chisel + direct drilling improved rooting depth of maize on plots from both rice-based and maize-based systems but direct drilling was more effective than chisel + direct drilling. Rooting depth was less than 14 cm for maize when it was planted on plots from Native savanna treatment. The greatest value of rooting depth of about 40 cm was observed on the plots from maize + soybean (green manure) rotation. This observation indicates that incorporation of green manure significantly improved soil physical conditions for root penetration. Results on rooting depth on savanna plots indicate that savanna soils do not support adequate root penetration.

Table 22. Effect of direct drilling or chisel + direct drilling on grain yield of maize planted on plots that were under different treatments of Culticore phase I (Carimagua, Colombia). LSD values are at 0.05 probability level.

Tillage method	*Culticore phase I systems*	Grain yield ($t\ ha^{-1}$)	Rooting depth (cm)
Direct drilling	Rice monocrop – T1	3.29	15
	Rice + Cowpea (grain) – T2	3.71	17
	Rice + Cowpea (green manure) – T3	3.47	21
	Grass + Legumes pasture[1] – T5	3.70	34
	Native savanna – T4	1.28	9
	Mean	***3.09***	***19***
Chisel + direct drilling	Rice monocrop	3.22	20
	Rice + Cowpea (grain)	2.23	19
	Rice + Cowpea (green manure)	1.96	23
	Grass + Legumes pasture[1]	3.24	32
	Native savanna	1.15	12
	Mean	***2.36***	***21***
LSD $_{0.05}$		1.06	
Direct drilling	Maize monocrop – T6	3.80	34
	Maize + Soybean (grain) – T7	3.80	22
	Maize + Soybean (green manure) – T8	4.71	40
	Grass + Legumes pasture[2] – T10	4.24	36
	Native savanna – T9	1.64	13
	Mean	***3.63***	***29***
Chisel + direct drilling	Maize monocrop	2.04	20
	Maize + Soybean (grain)	2.69	14
	Maize + Soybean (green manure)	2.37	18
	Grass + Legumes pasture[2]	4.12	35
	Native savanna	1.31	9
	Mean	***2.51***	***19***
LSD $_{0.05}$		1.07	

[1] *Brachiaria humidicola + Centrosema acutifolium + Stylosanthes capitata + Arachis pintoi*
[2] *Panicum maximum + Glycine wightii + Arachis pintoi*

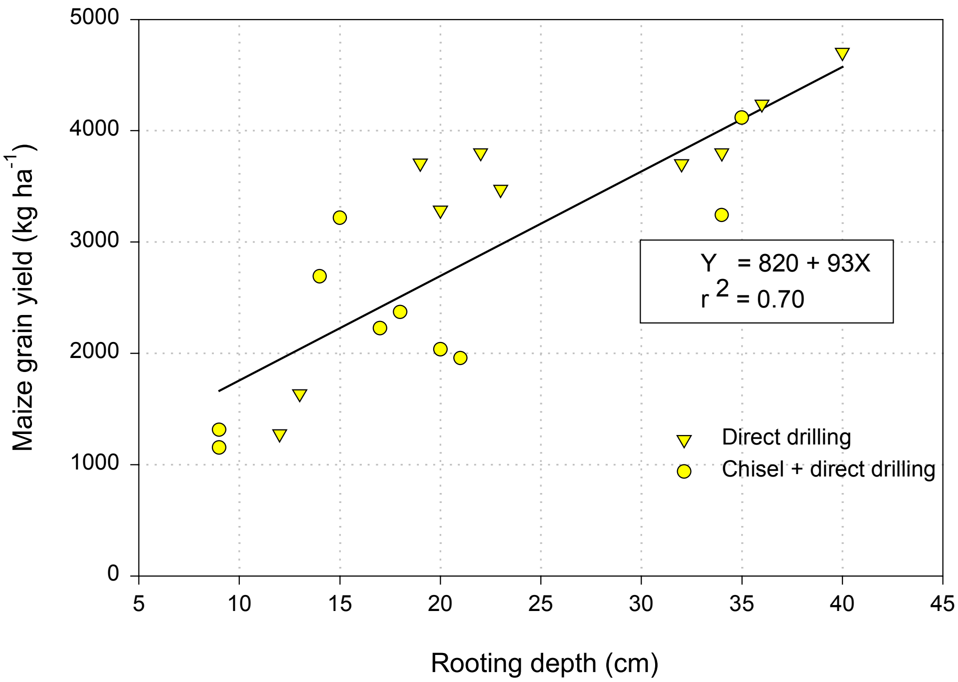


Figure 16. Relationship between grain yield and rooting depth of maize as influenced by direct drilling and chisel + direct drilling on plots that were under different treatments of Culticore phase I (Carimagua, Colombia).

Impact:
Results from this study illustrate the importance of improving rooting depth of maize to enhance crop performance and to sustain grain yields. This could be an important objective for maize breeders that are involved in developing acid soil adapted maize varieties and hybrids.

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Activity 1.6 Test compatibility of plant components in different systems (including farmer participation)

1.6.1 On-farm evaluation of green manures in Nicaragua

Highlights:

- Green manure evaluation sites established in 8 communities of San Dionisio
- Community field days carried out and key informants identified
- Participatory learning process initiated

Purpose:
To identify promising multipurpose legume components adapted to local conditions to be used in diversified cropping systems

Rationale:
Farmers are increasingly concerned about the market value of their harvest products in relation to increasing costs of purchased inputs. At the same time soil fertility on farmer fields is decreasing. Weeds become a larger problem over time. In order to overcome these limitations, with the support of CIAT, the local farmer organization "Campos Verdes" initiated a project to introduce, evaluate and promote the use of cover crops and green manures (CCGM) in the communities of San Dionisio. CCGM legumes may significantly contribute to enhanced soil fertility, water and soil conservation and weed suppression. Some of these green manure crops show high drought tolerance and can be used as forage or even for human consumption. It was also taken into account that growing CCGMs may result in a smaller amount of applied agrochemicals, which are already contaminating the scarce water resources of the people in San Dionisio. While plant adaptation/management and technical feasibility are important factors, economic viability is considered decisive for adoption. Therefore, cost-benefit analyses are one of the main objectives of the project in order to compare the current management including N-fertilizer and agrochemical application with the use of cover crops. Further objectives are the demonstration of the multiple uses offered by CCGM including their drought tolerance, participatory learning about CCGM, their management within the local community and the identification of key informants on local organic matter management techniques and indicators.

Materials and Methods:
A workshop was held in San Dionisio in April 2001 to which all members of Campos Verdes had been invited. A total of 27 farmers assisted the event and the proposed project was presented and discussed. Sites with different soil and climate conditions throughout San Dionisio were identified and CCGM options discussed. Farmers chose *Mucuna pruriens*, *Canavalia ensiformis* and *Lablab purpureus* as CCGMs for the experiment. At the end of September 2001 the experiments were established on 8 farms in different communities of San Dioniso (Table 23). The experiments consist of seven treatments which were arranged in a randomized block design with 3 replicates at each site. The treatments are summarized in Table 24. CCGM legumes were sown in maize plots (4 x 4 m) at the traditional bean sowing distance (0.4 x 0.4 m). Legume evaluation will be carried out on a monthly basis recording field emergence, plant height, ground cover, incidence of pests and diseases, weed presence, biomass production, drought tolerance, flowering patterns and seed production. Soil samples will be taken prior to the establishment of the experiments, prior to the maize planting and at the end of the experiments and analyzed. CCGMs will be kept in the maize plots throughout the dry season and maize will be planted into the CCGM mulch on the onset of the wet season. Fertilizer treatments will be applied and maize yields recorded. Pest, disease and weed incidence will be evaluated throughout the project. Cost-benefit analyses will be conducted and presented in a final workshop in November 2002. Field days will be held at strategic points of the project (legume establishment, legume drought tolerance, mulching and maize planting, maize harvest) in order to demonstrate and discuss practical management issues with the communities. By discussing soil fertility issues key informants for local soil organic matter management techniques and indicators will be identified and interviewed subsequently.

Results and Discussion:
Local on-farm evaluation data and economic analyses will be available for further promotion and dissemination of CCGM legume species. It is expected that a growing number of farmers in San Dionisio will adopt CCGMs technologies for growing maize in the future and will show further interest in other legume species. Local indicators for soil organic matter will be identified and the local knowledge on the management of soil organic matter documented.

Table 23. Location and site description of on-farm cover crop/green manure experiments in San Dionisio, Nicaragua.

Farmer	Community	Latitude	Longitud	Altitude	Observations
D. Salgado	Piedra Colorada	12° 49’ 47.2 N	85° 51’ 51.1” W	504	River valley
A. Castro	Susuli central	12° 48’ 29.2” N	85° 50’ 24.5” W	564	Slope
J. Hernández	Susuli arriba	12° 47’ 48.0” N	85° 50’ 05.2” W	565	Steep slope
V. Sevilla	Corozo	12° 47’ 02.2” N	85° 52’ 17.6” W	484	Slope
J. Orozco	Carrizal	12° 47’ 08.2” N	85° 54’ 15.0” W	715	Moderate slope
J. Jarquín	Piedras Largas	12° 43’ 32.6” N	85° 49’ 43.1” W	474	Slope
J. Hernández	Jícaro	12° 46’ 19.2” N	85° 50’ 15.6” W	530	Very steep slope
E. Ochoa	Ocote arriba	12° 43’ 00.4” N	85° 52’ 22.0” W	858	Slope

Table 24. Treatments included in on-farm cover crop/green manure experiments in San Dionisio, Nicaragua.

Treatment	Year 2001*	Year 2002
1	Maize	Maize without N-fertilizer (Control)
2	Maize	Maize with low N-fertilizer level
3	Maize	Maize with high N-fertilizer level
4	Maize	Maize with very high N-fertilizer level
5	Maize with *Mucuna*	Maize without N-fertilizer
6	Maize with *Canavalia*	Maize without N-fertilizer
7	Maize with *Lablab*	Maize without N-fertilizer

- Cover crops/green manures were sown into existing maize plots in September 2001when maize was entering its mature stage.

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