TECHNICAL PROGRESS REPORT

SOIL DEGRADATION AND CROP PRODUCTIVITY RESEARCH FOR CONSERVATION TECHNOLOGY DEVELOPMENT IN ANDEAN HILLSIDE FARMING

PROJECT No. 91.7860.9 - 01.112

CENTRO INTERNACIONAL DE AGRICULTURA TROPICAL-CIAT

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The Centro Internacional de Agricultura Tropical (CIAT); Cassava Program.

Principle Scientist: Dr. Rupert Best, Leader Cassava Program.

The University of Hohenheim, Institute for Plant Production in the Tropics and Subtropics.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table 2.22. Multiplication and distribution of hedgerow germplasm for soil conservation purposes until the end of 1994 [1]. Special project on Soil Conservation/Cassava Program.

ACRONYMS

CIAT	Centro Internacional de Agricultura Tropical
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria
FPR	Farmer Participatory Research
USLE	Universal Soil Loss Equation
OM	Organic matter
CETEC	Corporación para Estudios Interdisciplinarios y Asesoría Técnica
FIDAR	Fundación para la Investigación y Desarrollo de la Agroindustria Rural
CVC	Corporación Autónoma Regional del Valle del Cauca
IBSRAM	International Board for Soil Research and Management
FEDECAFE	Federación Nacional de Cafeteros de Colombia
NARs	National Agricultural Research Institutions
NGOs	Non-Governmental Organizations
GIS	Geographic Information System

1. SUMMARY

1.1. Background and Introduction.

Soil erosion is by far the most important factor of soil degradation in tropical hillsides where rainfall characteristics are favouring soil erosion (Hudson, 1971), and already have led to severe damage (El Swaify et al, 1991). Increasing cultivation of marginal, steep lands leads to accelerated levels of soil erosion with reductions of fertile topsoil where only crops with high levels of resistance to environmental stress can be grown successfully. One of the crops frequently found under these conditions is cassava but under marginal conditions it also shows slow initial development, soil cover and favours further degradation of the land (Howeler, 1985).

CIAT Cassava Program scientists therefore have been actively engaged in applied soil conservation research on hillsides for several years. These efforts have been strengthened in the past years through a collaborative research project with the University of Hohenheim, financed by BMZ, allowing CIAT to continue this research activity which otherwise could not have been continued because of the loss of a soil scientist and an agronomist position in the Cassava Program.

Earlier research concentrated on collecting basic information on erosion processes on two locations in the mid altitudes of the Southern Colombian Andes, on soil characteristics and first data on climate, based on the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978). Results showed high variability of erodibility and soil losses, values sometimes departing considerably from calculated figures, suggesting the collection of long term data to obtain conclusive, consistent results on the applicability or adjustment needs of the USLE for this Andean environment.

As a second major objective of the previous project, studies were conducted on the effect of management systems and cultural practices on soil losses and cassava productivity, the work focussing on tillage practices (Reining, 1992) and forage legume intercropping (Ruppenthal, 1995).

As a result promising options like live grass barriers, contour ridges and covers with less competitive forage legumes could be identified and characterized as regards to their erosion potential. More extensive and detailed research was suggested to judge innovative systems with respect to competition mechanisms and productivity. On farm activities to complement on station research on conservation component development was initiated since 1992 to include farmer's interest and point of view in the process of technology generation.

Collaboration with non-governmental and semiofficial organizations was sought to enhance technology adoption and development.

1.2. Project objectives.

A first three years project, succeeding two years of work of a Ph.D. student was finished in 1993. Main goals for the new project on "Soil Degradation on Crop Productivity Research in Andean Hillside Farming" were to:

a) better characterize and understand basic processes governing soil erosion and improve predictability of soil erosion;

b) to investigate relationships between soil degradation and crop productivity to translate erosion into terms of productivity for economists and policy makers and

c) enhance technology testing and development through on station research and intensified collaboration with local institutions and farmer groups.

Evaluations on runoff plots concentrated on contrasting rotation elements and their immediate and residual effects on soil erosion and productivity.

In conducting research along these lines the project is contributing to CIAT's new initiative on resources management research and to the integration of commodity based research with the new resources management programs.

1.3. Expected outputs and outputs met.

Work on erosion plots in Santander de Quilichao and Mondomo according to the USLE methodology was continued and data from previous measurements were analyzed throughout 1993 to 1995.

Analysis of rainfall characteristics could show that erosivity of rainfall, acts as the main cause of soil erosion in the project area. In Quilichao and Mondomo more than 60% and 50% of rainfalls were classified as erosive and more than 20% of total rainfall exceeded intensity ranges of 50 mm^{-h} sustained for 30 minutes. Not all "erosive" rains, however, did also cause erosion when soils were recently tilled or after prolonged dry periods. Average R-factors for erosivity of rains varied between 5000 and 11.000 $Mg.ha^{-1}.mm.\ h^{-1}.yr^{-1}$ over the last six years.

Average erosion potential measured on bare fallow plots in Quilichao and Mondomo was about 150 t of dry soil per ha and year in Quilichao and about 100 t/ha in Mondomo. Approximately 10-12% of rainfall was lost by runoff on bare plots and 4-6% on cultivated plots. Nevertheless in single events up to 60-70% of rainfall could be lost as overflow.

Correlations between rainfall indices for describing the aggressiveness of rainfall and soil losses increased over time, probably as a result of progressive soil degradation. The USLE R-factor, considering rainfall energy and intensity over 30 minutes (I_{30}) gave satisfactory correlations with measured erosion (r=0,81-0,90) but could be further improved by an index based on rainfall amount and the square of I_{30} (r=0,86-0,90) which at the same time is very easy to calculate from basic climatic data.

Work on the rainfall intensity-energy relationships has started in 1994 and needs further data collection.

Based on data from 7 years, erodibility of Inceptisols in the northern Cauca can be classified as low to moderate in Quilichao and low in Mondomo, values comparing well with those of many tropical Oxisols and Ultisols. K-factors on this highly aggregated soils also turned out to be very dynamic with an increase over time and a strong tendency to underestimate the erosion. With low rainfall K-values were significantly lower than with high rainfalls which means that in practice erodibility K was not independent from rainfall. From the data collected so far it is concluded that calculated USLE values for K (contrary to R-factors) are not adequate to predict soil erosion in a reasonable manner on these well aggregated soils.

An attempt was therefore made to find better ways to calculate erodibility K more accurately from a set of easy to determine, mainly soil physical parameters from the topsoil layer.

From a set of over 26 variables tested and analyzed, six parameters with high correlations to soil losses on both experimental sites were selected for multiple regression analysis. As a result of this exercise a model equation, mainly based on proportions of stable aggregate fractions and to a lesser extent on soil texture could be formulated, that explained 83 percent of the experimentally determined soil losses. Furthermore, infiltration measurements with the double ring method could be replaced by measurements of hydraulic conductivity in the topsoil, improving the accurateness of prediction.

Given the relative high importance of soil aggregates in the erosion dynamics of these Inceptisols it was also of much interest how soil aggregation is related to differences in soil management and cropping practices.

If not disturbed by intensive tillage, reseeding operations and human traffic in cut and carry operations (Ruppenthal 1995), intercropping of legumes favored the formation of water stable aggregates in cassava. Similar effects on aggregate stability could also be obtained by growing cassava on ridges (probably due to frequent drying and wetting).

Two year rotation elements with grass/legume mixtures had an even more pronounced effect on soil structure, the effects being more persistent than those of two year enriched weed fallow. This indicates, that intensification of land use, planting productive grass/legume mixtures instead of economically unproductive fallow is possible at the same time reducing risk of soil erosion.

Organic matter content, though generally related to erodibility was often a poor indicator of changes in soils erodibility as a consequence of different land use. Therefore research was initiated to look for other indicators to detect short term changes and to better interpret cropping systems with regard to their effects on soil erodibility. So far soils resistance to raindrop impact and certain fractions of carbohydrates could be identified as promising indicators.

Soil chemical properties on bare fallow plots were altered dramatically over the years resulting in a fast decline of soil organic matter, base saturation, loss of soil nutrients and acidification as a result of soil exposure and losses in sediment and runoff.

On cropped plots with lower levels of erosion soil chemical characteristics could be maintained or even improved over time when applying moderate levels of dolomitic lime and fertilizers. It was concluded that these soils with excellent physical characteristics can probably tolerate moderate levels of soil erosion over quite a long time period if nutrients are constantly replenished. On the other hand degradation might be accelerated if erosion is accompanied by nutrient depletion and acidification.

This could also be shown very clearly in experiments conducted at Quilichao to quantify the impact of erosion induced soil degradation on crop productivity.

Results obtained from growing sorghum and peanut on soils with different levels of erosion or soil removal, showed very severe yield reductions on oxic Dystropepts. Even large amounts of fertilizer could not compensate the loss of only 5 cm of top soil in the case of Sorghum. For peanut which reacted somewhat less sensitive, yield reductions were still very drastic, the impact of real erosion processes being stronger than those simulated through scalping. When erosion had removed the top soil layer to a depth greater than 13 cm or when soils were scalped to that same depth, this resulted in total yield losses when no fertilization was applied and in extremely poor yields with complete soil amendment.

Soil organic matter, N, K, inorganic P and aluminum saturation were soil chemical characteristics with highest correlations to yield reduction.

Once the complete data sets are available they will permit to relate erosion to economic losses or additional input requirements and allow to counterbalance these figures with costs implied with adequate programs to promote soil conservation.

Research on development of soil conservation effective cropping systems was guided by the dual goal of creating productive, income generating cropping technology, at the same time reversing the trend of soil degradation in hillsides.

Soil losses of cropping systems tested were consistently low in cassava grown on ridges, cassava with contour strips of grasses and in cassava/legume cropping systems, once the legumes had been well established (after 3-5 months or in the second growth cycle of intercropped cassava with zone tillage).

Cassava as a sole crop with tillage, with downslope ridges and with recently established legumes normally led to high soil losses (10-50 t/ha per year). Minimum tillage normally also gave reasonable levels of erosion control but typically led to high yield losses. This was also the case for cassava with forage legumes, once these were well established and productive.

Nevertheless, recent results have shown, that less competitive legumes exist (e.g. *Chamaecrista rotundifolia*), which allow high productivity of cassava, at the same time controlling erosion. Reduction of yield losses with minimum tillage could also be reduced to low levels or yields even be improved, when minimum tillage (zone tillage) was done after a two year grass/legume rotation element, killing the grassland with a herbicide before cassava planting. Yield losses for cowpea and cassava were also minimal or non existent when growing cassava or cowpea between Vetiver grass barriers, planted 8 m apart.

Besides short growth and biomass production less competitive root systems seem to be of high importance to reduce competition between cassava and legumes or barrier grasses as this could be shown by relating root morphology to competition.

With respect to grass barriers, several species with good adaptation to acid low-P soils could be identified. Besides Imperial grass (*Axonopus scoparius*) already used to some extent in the project region, these were Elefant grass (*Pennisetum purpureum*), Citronella (*Cymbopogon nardus*), Vetiver (*Vetiveria zizanioides*), Guatemala grass (*Tripsacum andersonii*), Partiña grass (*Andropogon leucostachyus*) and on slightly better soils Lemon grass (*Cymbopogon citratus*). Dwarf Elefant grass (*P. purpureum cv. Mott*) also performed surprisingly well. Because of higher palatability, convenience of harvest and lower growth height compared to normal Elefant grass it is now widely requested by farmers and local organizations as sole and barrier crop.

Collaboration with farmers and local institutions active in the area of natural resources management was developed and maintained throughout the years to stimulate a two way information flow between research and practice in the field, at the same time enhancing efficiency on both sites.

At present three on farm experiments with runoff plots including ditches for collection of eroded soil, three plots for multiplication of conservation germplasm and five plots for evaluating innovative or improved cropping practices are supervised and managed together with farmers and collaborating institutions.

Linking production of raw materials from conservation barriers to agroindustrial activities is most advanced in the Citronella sub-project where a woman's group of farmers has already set up a plant for essential oil extraction with technical support from FIDAR (NGO) and financial support from the project. CETEC another NGO linked to the project is formulating a project for broom fabrication based on the use of Partiña grass, which at the same time is promoted as a barrier option in the municipality of Buenos Aires/Cauca.

Interactions with the National Coffee Federation comprises the participation in training courses for farmers and the supply of basic quantities of conservation germplasm for multiplication and use by small coffee producers.

Contacts to National Cassava Programs in Brazil and Ecuador have also been established through visits and they will send scientists for in service training to CIAT in October 1995.

Economic evaluation and assessment was done for the Citronella oil extraction based on raw material produced in barriers and economic evaluation of other barrier components is under way based on extensive collection of biophysical data on production and labor requirements in the Cauca Department.

An intensive diagnostic study on farmers situation and attitudes related to aspects of soil conservation and soil fertility management were also undertaken in two municipalities on over 100 farms.

Training activities in the project included students training and training of farmers and visitors. Two Ph.D. students and one Master Student were trained and did or are doing their field research in the project. Five graduate students will also have finished their thesis work by the end of the ongoing project.

Training of farmers was mainly done through field days with collaborating NGOS, with CVC and through visits of farmers to the experimental station in Quilichao where over 500 visitors have been received.

Dissemination of potentially useful germplasm and of information generated through research was actively promoted by the project.

Results from project research is documented in sixteen written documents comprising thesis work, monographs, proceeding articles and technical papers.

1.4. Implications for transformation of results into development and further research needs.

As most of the technologies for soil conservation and sustained production do not show immediate impact in terms of yield gains or income improvement a careful strategy to translate technology into development or development politics is suggested, taking into consideration the following points:

- Concentrate on best options in terms of production and conservation.
- Support institutional infrastructure and logistics to promote convenient adoption by farmers.
- Continue research to enhance economic attractiveness of conservation components and to alleviate constraints identified.
- Link technology development to multidisciplinary work on production, product and market development, departing from a farmer's point of view.

The approach so far follow by the project to start from basic research at the same time developing components and testing them in systems was beneficial to the strategy outlined above. A still more interactive and multidisciplinary approach is however required to allow for a better ex-ante analysis of components, once these are developed to the stage of technical feasibility.

Further research needs in the area of more basic aspects for soil conservation technology development comprise:

- more work on the energy/rainfall intensity relationships and on soil water aspects.
- work on indicators of biologically induced changes of soil properties related with less erodibility and how these are be influenced by soil/crop management.
- identification of anatomical and physiological features of plants/components related with less competition and higher farmer acceptance.
- economic evaluation of conservation technology and testing of components in farm models, including market opportunities.

In the area of applied research, on farm activities should be given priority to develop viable innovative system components. Technically feasible sowing equipment for small seeded legumes in hillsides should be developed.

Generic characterization of economic, social and institutional environments and constellations favouring conservation technology adoption should also be given more attention in the future.

2. RESULTS

As outlined in the Work Breakdown of the ongoing project, research and activities covered the whole range of technology development starting from the generation of basic knowledge to the execution of productivity trials with farmers and NGO's and preparatory work for impact analysis based on diagnostic studies in two pilot areas. Results of ongoing work are presented according to the envisaged outputs of the project.

2.1. Predictability of soil erosion on Andean Inceptisols.

Work on erosion plots started in 1987 and was continued throughout 1993-1995. Data were collected and evaluated according to the procedures established for the application of the Universal Soil Loss Equation (USLE) developed in the USA by Wischmeier and Smith (1978).

In this empirical model soil losses A are expressed as the product of a series of factors determining the magnitude of the process and which at the same time are closely related to agronomic practices.

The USLE is: $A = R * K * C * L * S * P$ whereby A denotes soil loss (Mg/ha and year), R the rainfall factor, K the soil erodibility factor, C the cropping factor, LS the topographic factor and P the support practices factor.

Major goals for the reporting period were to a) follow up on generating long term soil erosion data related to soil properties, soil dynamics, climatic conditions and cropping practices and b) to examine the model as to its applicability to a tropical Andean environment where heavy rainfalls of high intensity are much more frequent and where soils differ considerably from those found in temperate climates.

Two sites with uniform slopes between 7-13% in Santander and 13-20% in Mondomo were chosen for the establishment of a total of 40 erosion plots.

- Santander de Quilichao (STQ), 3° 6'N, 76° 31'W; altitude 990 m; annual precipitation bimodal, 1809 mm; potential evaporation 1589 mm; average temperature 23.8°C; soil classified as amorphous, isohyperthermic oxic Dystropept.

- Mondomo (MO), 2° 53'N, 76° 33'W; altitude 1450 m; annual precipitation bimodal, 2133 mm; average temperature 18.2°C; soil classified as kaolinitic-amorphous, ishohyperthermic oxic Humitropept.

Bare fallow plots for experimental determination of soil erodibility and rain erosivity were 22.1 m in length and 8 m in width whereas other plots for the evaluation of cropping systems performance were 16 m long and 8 m wide.

Soil chemical and physical soil characteristics used as baseline information for the calculation of most of the data presented are shown in Table 2.1.

2.1.1. Characteristics of climate and rainfall erosivity, R.

Amount and intensity of rainfall, and so its kinetic energy, are generally much higher in the tropics than in temperate regions. The high erosion potential in the tropics is attributed more to high rain erosivity than soil erodibility. High intensities exceed infiltration rates easily, even on very permeable soils such as those found on the study sites, causing runoff and soil loss. Soil aggregates are broken up by raindrop impact, particles block soil pores or are moved downward by splash and runoff water.

Table 2.2. shows results from rainfall amount and rainfall characteristics from 1987/88 to 1992/93 (periods from 1993 to 1995 are still in the process of analysis).

Whereas in temperate climates only about 5% of the rainfall exceeds the intensity of 25 $mm.h^{-1}$, above which rainfall is considered to be erosive (Hudson, 1971), in Quilichao and Mondomo about 40% of the events passed the value.

Percentage of erosive rainfall according to USLE was even higher and reached levels between 44 to 80% (Table 2.2.)

In the 1990-1992 period more than 20% of the total rainfall fell at intensity ranges of over 50 mm^{-h} sustained for 30 minutes.

Not all rainfall considered as erosive (> 25 mm or exceeding intensities of 30 mm^{-h} over a 30 minute time interval) caused erosion. About 25 percent of these events, mainly after recently tilled soil or dry conditions did not cause erosion on the bare fallow plots.

Compared to mean soil losses with an annual average of about 150 t in Mondomo and about 110 t in Quilichao over the last seven years, the proportions of rain lost by runoff were relatively low. Minimum estimates (some overflow could be observed with some rainstorms) corresponded to about 12% in Quilichao and about 11% in Mondomo and were equivalent to 217 mm and 234 mm a year. However maximum runoff losses for single events reached levels as high as 70% and 53% in Quilichao and Mondomo respectively. In critical periods of crop development these losses easily can have an impact on yield formation and avoiding these losses can result in yield increase as it was shown for Vetiver barriers (see section 2 4.2).

Table 2.1. Some chemical and physical properties of top soils (0-20 cm) and infiltration rates of permanent bare fallow, cropped and uncultivated soils in Santander de Quilichao and Mondomo[1].

		Quilichao			Mondomo		
		Bare fallow	Cropped since 1986	Grassland soil	Bare fallow	Cropped since 1987	Bush fallow[2]
Ph (1:1)		4.1	4.5	4.6	4.3	4.6	4.7
org.matter %		5.3	6.0	7.3	4.4	6.3	7.1
Total N	$mg.kg^{-1}$	1923	2218	2072	1708	2053	2352
Mineral N	$mg.kg^{-1}$	56	51	51	63	67	70
Bray II-P	$mg.kg^{-1}$	3.9	14.3	1.4	9.3	9.3	3.9
K	$cmol.kg^{-1}$	0.08	0.17	0.16	0.22	0.22	0.29
Ca	$cmol.kg^{-1}$	0.20	1.44	0.85	1.35	1.35	1.10
Mg	$cmol.kg^{-1}$	0.05	0.54	0.30	0.48	0.48	0.56
Al	$cmol.kg^{-1}$	4.78	3.24	4.03	2.13	2.13	2.90
S	$mg.kg^{-1}$	81.3	64.0	39.3	63.5	63.3	65.0
B	$mg.kg^{-1}$	0.24	0.30	0.22	0.15	0.29	0.37
Cu	$mg.kg^{-1}$	0.71	0.77	0.72	0.96	1.04	0.49
Zn	$mg.kg^{-1}$	0.52	0.76	0.59	0.57	0.67	1.40
Mn	$mg.kg^{-1}$	2.1	9.2	8.8	88.6	55.0	25.1
Fe	$mg.kg^{-1}$	36.7	30.1	37.9	26.2	33.4	18.6
Sand	%	23.3	20.2	24.6	24.9	24.2	35.6
Silt	%	17.5	19.3	19.2	19.0	20.3	26.0
Clay	%	59.2	60.5	56.2	56.1	55.5	38.4
Infiltration rate[3]		5.9	3.5	4.8	4.9	12.7	8.3
Bulk density[4]		0.99	1.00	1.03	0.99	0.98	0.87
Degree of aggregation[5]		77.3	79.5	93.0	60.0	66.9	85.7

[1] Values are means of three replications in Quilichao and two in Mondomo and of two depths per plot (0-10 cm and 10-20cm).

[2] Only one replication was considered for bush fallow soils in Mondomo. The second one was used as a home garden before, which received chicken manure. Its soil properties are not representative for the typical cassava soils in the region.

[3] Final rates in $cm.ha^{-1}$

[4] $g.cm^{-3}$

[5] Percentage of particles > 0.5 mm, determined with a modified YODER method (Franco and Gonzalez, 1967)

Table 2.2. Characteristics of rainfall and USLE R-factors in Santander de Quilichao and Mondomo.

Rainfall and kinetic energy						
	Cropping season	Total rain (mm)	% erosive[1]	No. USLE-events	Kinetic energy ($J.m^{-2} mm^{-1}$)	R-Factor [7]
Santander de Quilichao	1987/88	1458.1	80.2	39	21.3	-
	1988/89	2416.8	77.8	58	21.3	-
	1990/91	1529.1	63.9	49	21.2	9042
	1991/92	1654.0	65.4	44	21.7	11078
	1992/93 [6]	1100.0	-	21	21.9	4957
	Average	1809.0[2]	72[3]	48[3]	21.5[3]	-
Mondomo	1987/88	1498.4	71.2	41	20.3	-
	1988/89	2376.6	73.9	55	20.5	-
	1990/91	1261.3	68.6	38	21.7[5]	7548
	1991/92	1274.5	45.9	31	20.1	5142
	1992/93	1200.0	-	19	22.1	5080
	Average	2133.0[4]	64.9[3]	41[3]	20.9	-

1 USLE events are rains, which fulfill the conditions, outlined by Wischmeier and Smith (1978) for R-factor calculations.

2 Mean of 23 years

3 Mean of five cropping seasons

4 Mean of 16 years

5 21.5 $J.m^{-2}.mm^{-1}$ for 80% of the rainfall. For reasons of reparation of the raingauge in 1990-1991 in Mondomo, four heavy rainstorms had to be excluded. Their kinetic energies were estimated.

6 February/92-February/93 - Dry period

7 $Mj.ha^{-1}.mm.h^{-1}.yr^{-1}$

With respect to the applicability of the USLE R-factor and/or alternative indices to characterize erosivity of rains, precipitation and erosion data processed so far were submitted to intensive analysis and results are shown in table 2.3.

The table shows, that correlation of erosion with rainfall increased over time on the bare fallow plots. From this it might be concluded, that soil erosion on these soils is governed more and more by rainfall characteristics as soil physical deterioration increases and soils inherent, modifiable resistance against erosion decreases. Aspects of soil structure seem to have much more influence on the erosion process than aspects of soil texture.

Indices including rainfall amount and/or energy combined with rainfall intensity over 30 minute time interval had the overall best correlations with soil erosion and the indices could even be improved by using the square of I_{30} - a procedure which normally improves predicting capacity of erosivity indices if rill-erosion plays a major role (see I_{30} values of Quilichao against indices with I_{30}).

With highly significant correlation coefficients of up to 0,88 and 0,89 for both study sites the USLE R-factor can be considered as a satisfactory erosivity index for this environment though A-I_{30} is still more accurate and also has the advantage of being easy to calculate from basic USLE data.

In the USLE model kinetic energy of rain and hence the determination of erosivity R is derived from intensity-kinetic energy relations found for temperate rainfall. Application of this functional relationships based on drop size data may however be of limited applicability in the tropics as this varies with location over the world (Hudson, 1971). Drop size measurements with standardized medium in splash caps have therefore been undertaken during one year in Santander de Quilichao but the database still is not representative enough to allow general conclusions. Accurate clarification of the unit rainfall energy - intensity relationships on this site needs further measurements to be able to obtain conclusive results.

2.1.2. Soil erodibility.

Erodibility measured on permanent clean tilled fallow plots under natural rainfall are classified as low to moderate in Quilichao and low in Mondomo. K-factors compare well with those of many Oxisols and Ultisols in the humid tropics.

Not untypical for the tropics, this means that erosion on these Inceptisols is mainly governed by the erosivity of rainfall and to a lesser extent by soil erodibility.

Testing the USLE allowed to detect changes over time in major soil parameters influencing and modifying the erodibility K of the soils which in the USLE is assumed to be a constant value.

Table 2.3. Coefficients of correlation (r) for the relationship between soil loss from permanent bare fallow plots and selected erosivity indices in Santander de Quilichao and Mondomo

	Santander de Quilichao			Mondomo		
	1987-1988	1988-1989	1990-1992	1987-1988	1988-1989	1990-1992
Indices of erosivity		r			r	
A	0.35^{ns}	0.29^{ns}	0.57^{***}	0.03^{ns}	0.48^{*}	0.75^{***}
E_u	0.36^{ns}	0.40^{*}	0.64^{***}	0.05^{ns}	0.56^{*}	0.78^{***}
KE>25	0.41^{ns}	0.59^{**}	0.71^{***}	-0.0^{ns}	0.75^{***}	0.76^{***}
I_{15}	0.53^{ns}	0.56^{**}	0.67^{***}	0.06^{ns}	0.80^{***}	0.62^{***}
I_{30}	0.56^{*}	0.67^{***}	0.77^{***}	-0.09^{ns}	0.79^{***}	0.76^{***}
I_{45}	-	-	0.76^{***}	-	-	0.72^{***}
I_{60}	-	-	0.72^{***}	-	-	0.69^{***}
$A \cdot I_{15}$	0.48^{ns}	0.68^{***}	0.77^{***}	-0.01^{ns}	0.79^{***}	0.88^{***}
$A \cdot I_{30}$	0.45^{ns}	0.71^{***}	0.80^{***}	-0.06^{ns}	0.72^{***}	0.90^{***}
$A \cdot I_{45}$	-	-	0.77^{***}	-	-	0.87^{***}
$A \cdot I_{60}$	-	-	0.73^{***}	-	-	0.84^{***}
$E \cdot I_{15}$	0.49^{ns}	0.73^{***}	0.79^{***}	-0.22^{ns}	0.80^{***}	0.88^{***}
$E \cdot I_{30}$	0.49^{ns}	0.75^{***}	0.81^{***}	-0.05^{ns}	0.80^{***}	0.89^{***}
$E \cdot I_{45}$	-	-	0.79^{***}	-	-	0.86^{***}
$E \cdot I_{60}$	-	-	0.75^{***}	-	-	0.84^{***}
$E_u \cdot A \cdot I_{30}$	0.45^{ns}	0.83^{***}	0.77^{***}	-0.24^{ns}	0.75^{***}	0.93^{***}
$A \cdot I_{7.5}$	0.42^{ns}	0.68^{***}	0.75^{***}	0.18^{ns}	0.79^{***}	0.86^{***}
I_{30}^2	-	-	0.85^{***}	-	-	0.81^{***}
$A \cdot I_{30}^2$	-	-	0.86^{***}	-	-	0.90^{***}
$E \cdot I_{30}^2$	-	-	0.86^{***}	-	-	0.89^{***}
EIA	-	-	0.95^{***}	-	-	0.93^{***}

A = rainfall amount
E_u = kinetic energy of rainfall (USLE)
KE>25 = kinetic energy of all increments of a rain storm with intensities >25 mm/h
I_n = maximum intensity of a rain storm sustained during minutes
$A \cdot I_{7.5}$ = $A \cdot I_m$ (Lal, 1976)
EIA = $(A \cdot \text{Runoff volume})^{0.5} \cdot I_{30}$

Table 2.4. shows an increase in erodibility in the course of the years which means that erosion risk on these soils increased with prolonged tillage and exposure and the degradation of soil characteristics relevant to erodibility. Only in the last year with very few erosive events and probably also influenced by soil aggregation through binding mineral agents (sesquioxides) soil erodibility descended again. Decrease of erodibility in the 1992/93 season is also pointing to a weakness of the USLE methodology, where erodibility K is not really an independent variable but influenced by rainfall erosivity R. This interdependency and dynamic nature of soil erodibility could also be shown to be dividing the K factors of events from two years in those of the dry season, giving an average value of 0,012 against a K factor of 0,019 in the wet season. This finding was also confirmed by other researchers (cited by Ruppenthal, 1994).

Also it is well known that erodibility values can vary a lot within the same soil order (Ruppenthal, 1994). On some tropical soils measured values compared reasonably well with values computed by the USLE nomograph (Roose, 1976) whereas serious discrepancies could be observed for soils with amorphous and oxidic constituents (El Swaify, 1977). On well aggregated soils the USLE nomograph predictions often underestimated K values and this was also the case in Quilichao and to a lesser degree in Mondomo, where the USLE procedure failed to predict erosion in a reasonable manner.

On aggregating soils, as those found in Quilichao and to a lesser extent also in Mondomo, the texture term M of the original USLE-nomograph seems of limited value. Therefore it was suggested to give more importance to soil structure (Röhmkens 1985), aggregate stability and the contribution of amorphous or oxidic constituents to structural stability in the K-prediction (El Swaify, 1977).

As it is shown below, this could be confirmed in an attempt to simplify and improve the prediction of K-values for these soils, based on a set of easy to determine, mainly soil physical parameters.

2.1.3 Estimation of K-values with new indices and role of soil aggregates

A main activity contributing to improve the predictability of erosion on Andean Inceptisols was the estimation of the erodibility factor K on the basis of a set of easy to determine, mainly physical soil parameters from the topsoil.

Based on project results (see above) that revealed a considerable discrepancy between predicted erosion, applying the USLE K-factor and measured erosion, an attempt was made to improve and at the same time simplify the prediction of erodibility.

This research was carried out in the framework of a masters thesis of the project's assistant in collaboration with the National University of Colombia in Palmira.

Table 2.4. Soil losses in $t.ha^{-1}$ and USLE erodibility factors K ($t.ha.h.ha^{-1}.Mj^{-1}.mm^{-1}$) in Santander de Quilichao and Mondomo, measured directly from permanent bare fallow plots.

	Santander de Quilichao		Mondomo	
Time period	K-factor [2]	Soil loss [1]	K-factor	Soil loss
1986-87	0,001	15,0	0,001	2,0
1987-88	0,004	49,2	0,003	44,5
1988-89	0,013	196,5	0,010	310,6
1989-90	?	165,0	?	190,0 [3]
1990-91	0,015	143,7	0,011	227,9
1991-92	0,018	222,6	0,012	160,1
1992-93 [4]	0,005	33,1	0,010	130,2

1) Uncorrected values as regards to slope
2) SI-units
3) Value for Mondomo were best estimates in this year
4) A year with very few rainfall and few erosive events of low mean kinetic energy.

Based on the hypothesis that the erosion process on these well drained hillsides is governed by the characteristics of the surface soil, sampling and soil characterization was done at the 0-10 cm surface in the 1992-1993 growing season. Reference data on soil characteristics of bare fallow plots were taken 2 1/2 years after the sampling for the thesis of Mr. Martin Ruppenthal and as data in Table 2.5. show, soil characteristics at the surface of the bare fallow plots had suffered considerable changes over this time period.

In Table 2.6. calculated and real (experimentally determined) factors of erodibility are shown. Because of the interrelationships between rainfall and soil losses in the USLE, also well documented in the thesis of Martin Ruppenthal (1995), low values of erosivity in this year led also to low experimental K values for erodibility.

Table 2.7. shows coefficients of simple linear regression between some soil physical characteristics and the experimental K-factor for theses soils. Whereas on the Mondomo site soil organic matter content and other parameters like the percentage of stable aggregate fractions showed more or less the expected correlations with the experimentally determined K factors, this was not always the case in Santander de Quilichao. On this site, complex interactions with or between other soil physical and chemical characteristics like the content of sesquioxides, typical of tropical soils, apparently had altered or masked the correlations.

Table 2.5. Some physical properties of the 0-10 cm topsoil of plots with a) continuous cassava; b) cassava forage legume and c) bare fallow USLE plots in Santander de Quilichao and Mondomo [1)]

		Porosity			Mechanical Analysis		
Plots	Organic matter %	Water %	Air %	MWD [2)] mm	% Sand	% Silt	% Clay
Santander de Quilichao							
a) Sole cassava	3.85	25.5	39.8	2.80	23	24	53
b) Cassava + Centrosema	4.10	27.0	37.9	3.83	27	24	49
c) USLE bare fallow	3.10	22.7	43.2	3.44	37	19	44
Mondomo							
a) Sole cassava	3.27	26.3	39.4	2.01	28	24	48
b) Cassava + Centrosema	3.22	27.0	36.0	2.55	30	24	45
c) USLE bare fallow	2.54	24.8	40.5	1.85	35	19	46

1) Treatment a) six years; treatment b) two years of cassava plus 4 years of cassava legumes; treatment c) six years bare plots.

2) Mean Weight Diameter of aggregates

Table 2.6. Calculated and experimentally determined erodibility factors (K) from soils of standard plots in Santander de Quilichao and Mondomo (Season 92/93).

Method	t.ha.h/ha Mg mm	Santander	Mondomo
Calculated	K [1]	0.111	0.102
	K [2]	0.047	0.005
Experimentally determined	K	0,005	0.01

1 After Wischmeier and Smith (1978) using constant infiltration rate

2 Using hydraulic conductivity

Table 2 7 Simple linear correlation coefficients (r) between experimentally determined K factors of erodibility and some physical properties of soils in Mondomo and Santander de Quilichao

		K			
		r	p	r	p
Independent soil variable	Symbol	Santander		Mondomo	
X1 Water stable aggregates, >2 mm (%)	WSA2	-0.28731	0.4535	-0.56129	0.1477
X2 Water stable aggregates, 1-2 mm (%)	WSA12	-0.04086	0.9169	-0.53868	0.1684
X3 Water stable aggregates, 0.5-1 mm (%)	WSA51	0.13044	0.7380	-0.44188	0.2730
X4 Water stable aggregates, 0.25-0.5 mm (%)	WSA255	0.00475	0.9903	0.59876	0.1168
X5 Water stable aggregates, <0.25 mm (%)	WSA25	-0.37974	0.3134	0.91451	0.0015
X6 Dry stable aggregates, > 2 mm (%)	DSA2	0.70162	0.0352	-0.20043	0.6341
X7 Dry stable aggregates, 1-2 mm (%)	DSA12	-0.51780	0.1533	0.16145	0.7025
X8 Dry stable aggregates, 0 5 - 1 mm (%)	DSA51	-0.73355	0.0245	0.29696	0.4751
X9 Dry stable aggregates, 0.25 - 0.5 mm (%)	DSA255	-0.44358	0.2317	0.13048	0.7581
X10 Dry stable aggregates, <0.25 mm (%)	DSA25	-0.67116	0.0478	0.26629	0.5938
X11 Proportion of water filled pores, (%)	PWP	-0.34713	0.3600	0.09709	0.8191
X12 Proportion of air filled pores, (%)	PAP	0.40351	0.2815	-0.05251	0.9017
X13 Mean weight diameter, MWD (mm)	MWD	0.29684	0.4379	-0.67779	0.0647
X14 Bulk density, (Mg/m^3)	BD	0.04353	0.9115	-0.01649	0.9691
X15 Constant infiltration rate, (cm/h)	CIR	-0.67353	0.1425	0.86238	0.0600
X16 Organic matter, (%)	OM	-0.06016	0.8778	-0.40282	0.3224
X17 Sand, 0.05 - 2 mm (%)	SANDP	-0.18100	0.6412	0.18111	0.6678
X18 Silt, 0.002-0.05 mm (%)	SILTP	0.11784	0.7627	0.10807	0.7989
X19 Clays, <0.002 mm (%)	CLAYP	0.14954	0.7010	-0.27777	0.5054
X20 Very coarse sand, 1-2 mm (%)	VCS	-0.48005	0.1909	-0.77554	0.0237
X21 Coarse sand, 0.5-1 mm (%)	CS	0.64423	0.0611	0.06470	0.8790
X22 Medium sand, 0.25-0.5 mm (%)	MS	-0.24447	0.5261	-0.63949	0.0878
X23 Fine sand, 0.10-0.25 mm (%)	FS	-0.18423	0.6351	0.13611	0.7479
X24 Very fine sand, 0.05-0.10 mm (%)	VFS	-0.35061	0.3549	0.51895	0.1876
X25 Clay proportion, X19/(X17+X18)	CP	0.14216	0.7152	-0.29302	0.4812
X26 Initial infiltration rate, (cm/h)	IR	-0.13628	0.7266	-0.59625	0.1187

p = P value of significance

A frequently applied and simple way of computing values of erodibility (K) consists in formulating equations, using easy to determine and independent variables of basic soil properties which are highly correlated with measured "K" values.

The method of deriving erodibility from a given set of soil properties is based on data from experimental plots which can be obtained by using rainfall simulators or still better, but more expensive and time consuming, by measuring soil losses from uniform runoff plots as they were used for this study.

As data on soil erodibility of tropical soils are not very abundant it is not easy to identify the most important soil properties to determine K. Moreover variability of only a small number of soils sampled, makes it a difficult task to relate erodibility to a few soil characteristics. On the other hand, complex models considering a large number of soil variables are of limited practical applicability and have mainly been developed for temperate climates.

Table 2.8. summarizes coefficients of stepwise multiple regression between values of erodibility and selected soil variables. In step nine, considering mainly different fractions of stable aggregates and soil texture, five variables could explain 83 percent of the measured erodibility. Considering the coarse sand fraction in step 10 improves the model estimate by another 5%. As this variable is easy to determine it is suggested to include the coarse sand fraction in the model.

As a result of this exercise the following two model equations are proposed to estimate the erodibility (K) of these soils:

1. $K = 0{,}037936 + 0{,}002974\ X5 + 0{,}00115\ X6 - 0{,}003001\ X2 - 0{,}036569\ X19 - 0{,}005283\ X4$.
2. $K = 0{,}047497 + 0{,}00287\ X5 + 0{,}00114\ X6 + 0{,}000341\ X21 - 0{,}003446\ X2 - 0{,}037605\ X19 - 0{,}006012\ X4$.

Based on the experience from these trials it is suggested to revise and study in more detail the indirect determination of erodibility K of these soils as suggested by Wischmeier and Smith. Experimentally determined K values for the soils in Mondomo and Santander de Quilichao were obtained in a relative dry period and were quite low but highly correlated with soil physical properties explored.

Using hydraulic conductivity data instead of constant infiltration rates obtained with the double ring method also led to an improved estimate of erodibility with these soils. It is therefore recommended to further explore this possibility on other sites, because the process of data collection is much easier and does not require to transport hundreds of liters of water to remote hillsides.

Table 2.8. Regression coefficients obtained in step 9 and 10 of stepwise multiple regression between K factors of soil erodibility and some independent soil variables of tropical Inceptisols in Santander and Mondomo/Colombia.

Variable	Coefficient of regression equation	R^2	Prob>F
Intercept	0.037936	-	0.0711
% water stable aggregates < 0,25 mm	0.002974	0.2043	0.0001
% dry stable aggregates > 2 mm	0.00115	0.6610	0.0012
% water stable aggregates 1-2 mm	-0.00300	0.7388	0.0003
Clay proportion; clay/silt + sand	-0.03656	0.7701	0.0598
% water stable aggregates 0,25 - 0,5 mm	-0.00528	0.8280	0.0079
Intercept	0.047497	-	0.0245
% water stable aggregates < 0,25 mm	0.00287	0.2043	0.0001
% dry stable aggregates > 2 mm	0.00114	0.6610	0.0008
% water stable aggregates 1-2 mm	-0.00344	0.7388	0.0002
Clay proportion in clay/silt + sand	-0.03760	0.7701	0.0378
% water stable aggregates 0.25 - 0.5 mm	-0.00601	0.8318	0.0029
% coarse sand 0,5 - 1 mm	0.000341	0.8757	0.0964

Whereas the alternative model for estimating K-values was developed on the basis of data from long term bare fallow plots parallel measurements were also executed on selected treatments. Main objective of this exercise was to explore the interactions between soil physical parameters relevant to the process of soil erosion and plant cover or soil management.

2.2. Better understanding of basic processes governing soil erosion.

From research done on the rainfall factor R and the soil erodibility K it is already clear that the relative importance of individual factors involved in the erosion process differs from those found for situations in the temperate zone. A better understanding of the commonalities and differences compared to erosion processes in temperate regions is therefore needed and forms the basis for the formulation of more effective strategies to reduce or stop hillside erosion in the tropics.

2.2.1. Role of soil aggregates and topsoil characteristics.

As search for alternatives to estimate soil erodibility "K" on this inceptisols revealed, soil aggregates and their distribution play a key role on this soils. Formation and presence of aggregates > 2 mm was significantly improved through long term legume intercropping in cassava.

After four years of legume intercropping highest Mean Weight Diameters of aggregates were always found in the cassava plus forage legume treatment, which suggests an aggregating effect of the legume intercrop and improvement of soil structure through better soil cover provided in this system (Fig. 2.1 and Fig. 2.2).

Enrichment of larger particles and aggregates also occurred on the bare fallow plots in Quilichao but in this treatment it was attributable to the selective process of intensive erosion and the surface accumulation of stable aggregates formed with iron and aluminum.

Cover legumes favored water infiltration whereas in cassava alone water runoff and hence also soil erosion was promoted by a lower proportion of aggregates > 0,25 mm.

Last results obtained from residual effects of contrasting two years rotation elements suggest that grass legume mixtures have an even more pronounced and longer lasting positive effect on soil aggregation (See paragraph 4) and can even outperform bush fallow, which means, that intensification of traditional land use is possible at the same time improving soils resistance against erosion- the key parameter of soil degradation in hillsides (see also Table 2.4.... and section 2.4.1.).

Aggregate analysis done in the years before could also show that contour ridging for cassava favoured the formation of stable big aggregates, probably because of the effects of frequent drying and wetting. Aggregate stability (MWD) was comparable to long years of grass fallow and superior to bush fallow.

Correlation analysis executed for the relationships of organic matter with aggregate stability on two sites with 6 cropping treatments plus bare fallow soils, gave only very poor correlations ($r = 0.41$, $P = 0.01$) which indicates that organic matter is a relatively poor indicator for the erodibility of these Inceptisols.

Erosion is governed mainly by two processes: the detachment of soil particles from aggregates by raindrops and subsequent transport of detached sediment with surface runoff as laminar overflow or in rills.

Disintegration of soil aggregates at the surface normally dominates the magnitude of erosion and therefore extensive measurements were also made on soils resistance to raindrop impact. The studies were undertaken in laboratory with a device producing raindrops of 4.5 mm diameter falling from a height of 2 m every 5 seconds. Aggregates exposed to raindrops were separated according to their size in four classes and placed on a 60 mesh sieve in rotating tubes.

Soil detachment by raindrop impact was higher for the Mondomo site than for soils of Quilichao (see figures 2.3 and 2.4). These values corresponded to experimental K-factors measured on the plots in a season where dry weather conditions with few

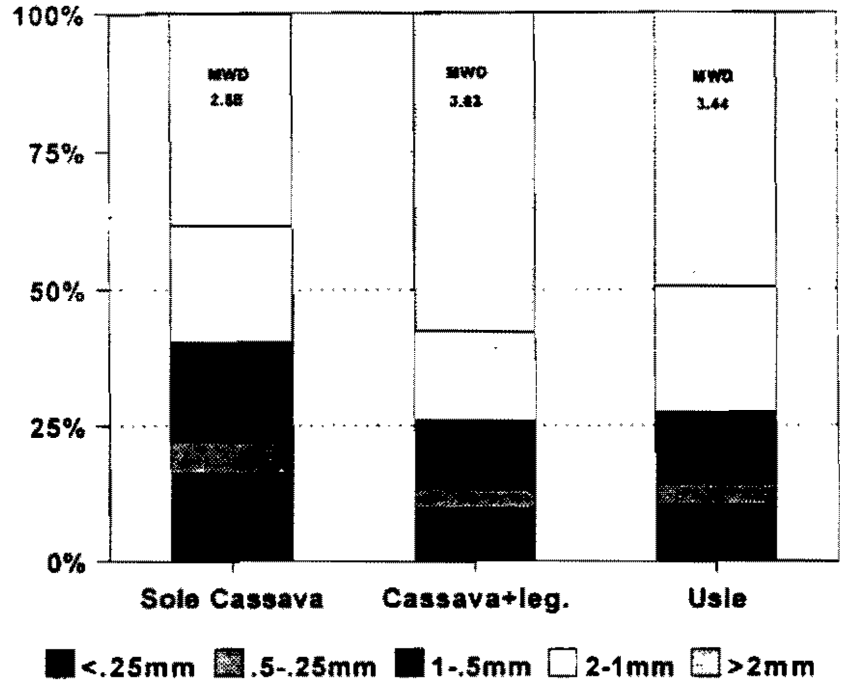


Figure 2.1. Distribution of aggregate sizes and Mean Weight Diameter (MWD) in the topsoil of trial plots in Santander de Quilichao as affected by land use practices.

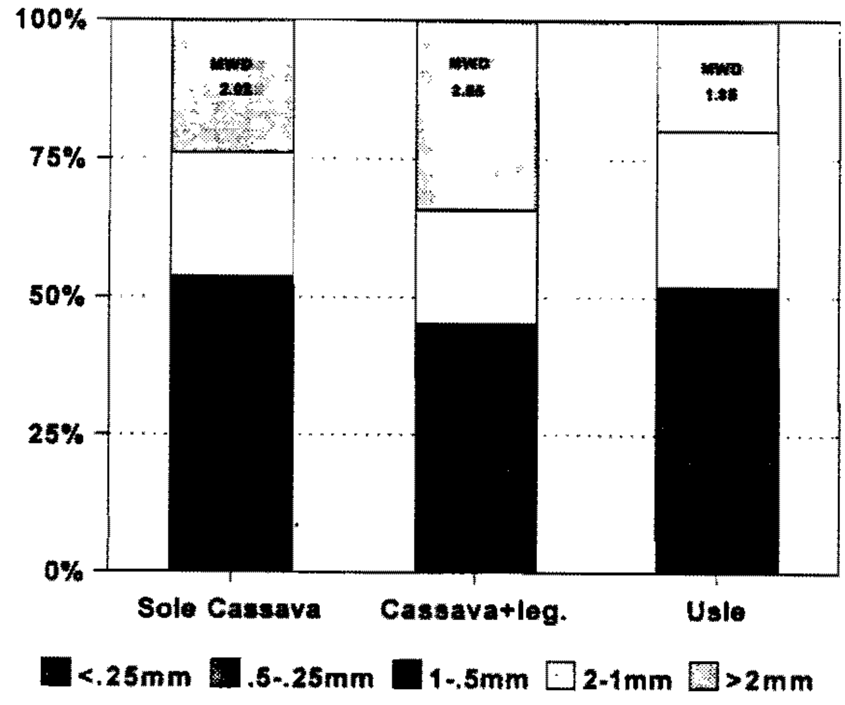


Figure 2.2. Distribution of aggregate sizes and Mean Weight Diameter (MWD) in the topsoils of trial plots in Mondomo as affected by land use practices.

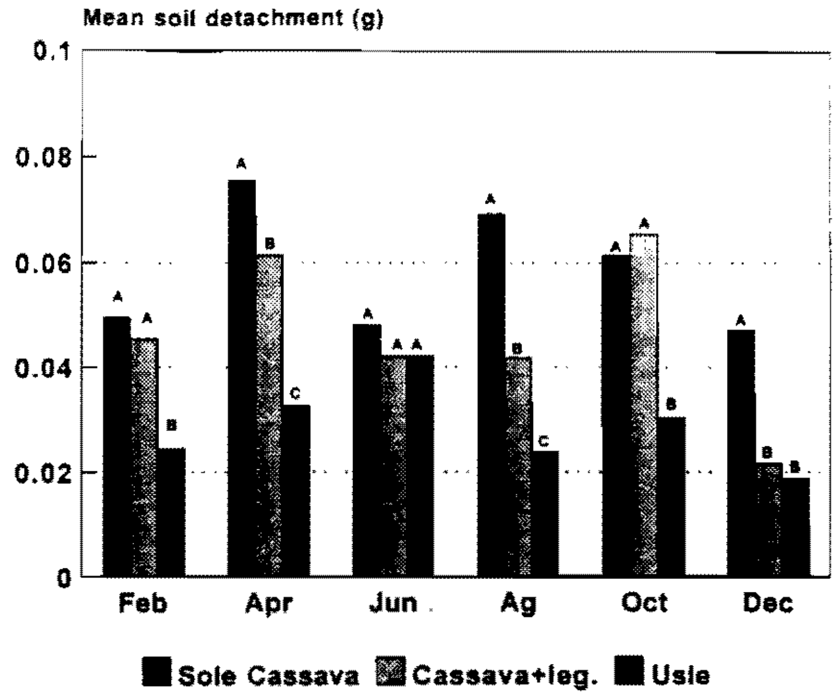


Figure 2.3. Soil detachment by raindrop impact from aggregate of the Santander de Quilichao soil. Sample size n = 24 for each column.

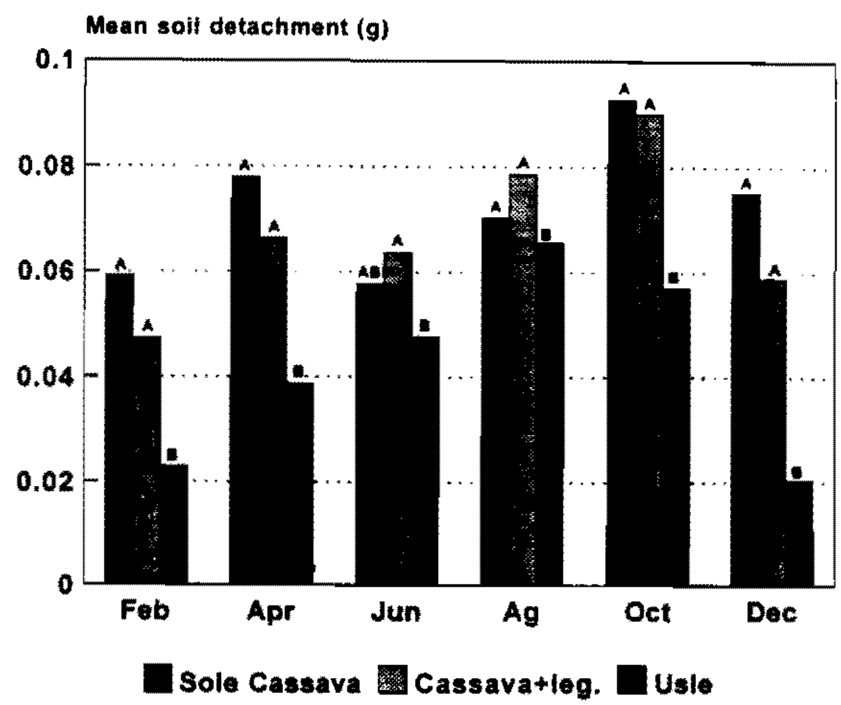


Figure 2.4. Soil detachment by raindrop impact from aggregate of the Mondomo soil. Sample size n = 24 for each column.

rainstorms prevailed.

Aggregates from the soil surface of six-year old USLE bare fallow plots were more resistant to raindrop impact than others, but were sensitive to soil losses caused by runoff in the form of rill erosion caused by intensive rainstorms. In Santander aggregates from cassava plots intercropped with forage legumes were more stable than those from sole cropped cassava. In Mondomo the same tendency could be observed, but differences were statistically not significant.

Additional data from trials with this method on four sites were collected in collaboration with two Colombian graduate students and will help to further clarify the suitability of this method for characterizing soil erodibility in this environment (Buritica and Polanco, 1994).

Preliminary evaluation shows consistency of results obtained from raindrop impact with data from measured erosion and once the device was installed, a lot of samples could be processed within a short time. Nevertheless, to reduce the high variability, a shift from "single drop" to micro rainfall simulators with bigger, more representative soil samples on plates is suggested in order to be able to obtain consistent data with a reasonable number of samples.

Identification and testing of other, practical indicators of improved aggregation of soils and less erodibility is also suggested for better monitoring of interactions between soils, erosion and plant cover or crop type.

2.2.2. Soil chemical changes.

As outlined in more detail in the following paragraph on erosion impact on soil productivity, tropical soils in general are more sensitive to erosion than soils of temperate climates. In the study region, as well as in large parts of South America topsoils with reasonable levels of nutrients and organic matter are overlying infertile acid subsoils. As a consequence tolerance limits for soil chemical degradation and nutrient losses are easily exceeded and make sustainable crop production a difficult task.

Theoretically, chemical soil fertility may be partly restored by mineral fertilizers, but in South America cassava is typically grown by poor farmers on marginal land and with marginal infrastructure. Thus this alternative is more of theoretical character and rotations and sustainable management practices constitute the only means of improving sustainability.

Eroded sediments typically are higher in organic matter and soil nutrients as they are carried primarily by finer particles and collides, which are more readily transported by water runoff. This effect is more pronounced on sandy soils and on purely structured soils and also with moderate levels of soil erosion. In these cases finer particles are selectively removed. In well aggregated soils of high clay content and during heavy rainstorms causing rill erosion, soil fractions are removed more evenly, leading to lower enrichment rations, defined as the ratio of the concentration of an element in the sediment to that in the source soil.

On the erosion plots under observation since 1987 heavy erosion on bare fallow plots led to severe decreases in concentrations of organic matter, total nitrogen, exchangeable Mg, Potassium and Bray II Phosphorus.

Loss of soil nutrients from cropped plots followed the same pattern as soil losses in different cropping treatments with a relative selectivity for impoverishment in Ca, Mg and Potassium.

During the first years of the experiment enrichment ratios for sediments from erosion plots were 1,5 for Mg and 1,4 for K and very low for organic matter and nitrogen (Reining, 1992). Three years later (Ruppenthal, 1994) enrichment ratios on this soils continued to be low on these Inceptisols (1,1-1,3).

Highest enrichment in nutrients was observed for Ca 1,3 and Bray II-P on bare fallow plots (1,5) and for Mg (1,2), K (1,3) in cassava-legume cropping systems.

These enrichment ratios are relatively low, when compared with results from other researchers in the tropics and can in part be explained by the high aggregation of the kaolinitic, amorphous soils, rich in clay and sequioxides. This might also be the reason for the relative enrichment of sand (1,2-1,3) in sediments from bare fallow plots.

Not all nutrients are however bound to eroded sediment but are also dilute in the runoff water, which accounted for 25 to 30% of the nutrient losses on bare fallow plots and for 74, 90 and 85 percent of P, K and Mg in the cassava forage legume treatments.

The high proportion of nutrients lost by surface water, contrary to most of the results found in the literature stress the importance of runoff control and water conservation to diminish nutrient losses and water contamination.

Very high nutrient concentrations in runoff water, subsequent to fertilizer application (Lal, 1976) could never be observed in the trials. The local practice of applying fertilizers in a rill in the upper part of cassava and covering it with a thin soil layer seems to be an effective method to reduce these losses.

Overall water losses on bare fallow plots were in the order of 10-12% on 10-20% slopes, equivalent to over 200 m per year. On cropped plots 4-6% of precipitation was lost as runoff equivalent to 60-100 mm with lowest losses in cassava grown on contour ridges.

2.2.3. Interactions between plant cover, soil and erosion.

Research on Inceptisols in southern Colombia once more demonstrated the overriding role of soil cover for the maintenance of good physical soil structure and the maintenance of adequate nutrient levels of hillside soils. The synergy between these leads again to an earlier more vigorous plant development, better soil cover, more biomass input, and less erosion.

As interactions between plant cover, soil and erosion are dealt with throughout the report only a few specific issues will be presented here and discussed.

With respect to soil organic matter, aggregate stability and nutrient depletion of the soils it could be clearly demonstrated that the absence of soil cover, by plants, weeds, mulch and intensive rooting leads to fast soil deterioration. In Mondomo within only 6 years pH fell from 4.7 to 4.4, organic matter from 7.7 yo 4.6%, total soil N (0-10 cm) from 2688 to 1624 $mg.kg^{-1}$, exch. Ca ($Cmol.kg^{-1}$) from 1,2 to 0,21 and exchangeable K from 0,32 to 0,07.

Accumulated soil losses on these plots with 15-20% slope reached 953 $t.ha^{-1}$ of dry soil equivalent to about 10 cm of soil.

Compared to this extreme from tilled bare fallow plots, cropping of these soils with different cassava cropping systems, combined with moderate liming (400 kg $CaCO_3$. ha^{-1}) and moderate fertilizer applications allowed to maintain or even improve (P) soil chemical characteristics compared to the initial situation. This was, however, not the case for soil physical properties. Here all cropping practices led to clear loss of structural stability but significant differences could be found between cropping treatments with respect to the magnitude of this phenomenon. Intercropping of forage cover legumes favoured soil aggregation, water infiltration and resistance of soils to raindrop impact but stabilizing effects from grassland or grass-legume crops on soil structure seem to be more pronounced. They have a longer lasting effect on reduction of soil erosion as could be shown recently by analyzing the residual effects of two years of contrasting rotation elements on soil aggregate stability during the following year (Table 2.9).

The importance of permanent or in the case of tillage, early soil cover to reduce soil erosion levels was clearly demonstrated in Mondomo where coincidence of heavy rainfalls and low soil cover of recently planted cassava led to 70 to 80% of the annual erosion losses. USLE-C factors for newly established Cassava-Zornia systems were as high as 1.44 in the first two month period.

Experience also demonstrated that on moderate slopes of about 5-15% ridges and/or contour lines of well established grass/grass-legume hedgerows can reduce erosion to

Table 2.9. Residual effects of two years of contrasting cropping treatments on the Mean Weight Diameter (MWD) of soil aggregates (0-20 cm) in Santander de Quilichao (Oxic Dystropept) and Mondomo (Oxic Humitropept) in the cropping season 1994-1995 with cassava as the main crop.

	Mondomo		Santander de Quilichao	
Precedent treatment (2 years)	MWD mm	Se[1)]	MWD mm	Se
USLE-Bare	1.96	0.08	2.00	0.11
Cowpea sole + Chicken manure (6 t/ha.yr)	2.85	0.15	3.11	0.36
Cassava sole	2.53	0.17	2.85	0.51
Improved weed fallow[2)]	3.05	0.36	3.15	0.39
Brachiaria + legume + minimum tillage	3.10	0.04	3.39	0.52

1) Standard error

2) Zornia glabra legumes had been undersown in previous cassava and were left after cassava harvest.

acceptable levels but above this combined strategies of runoff control (eg. hedgerows) plus improved soil cover and/or minimum tillage are needed to check erosion.

2.3. Impact of soil degradation on crop productivity.

Removal of topsoil by erosion affects physical and chemical soil characteristics and typically leads to nutrient losses, reduced water infiltration and water storage capacity. As a consequence yields decline and farmer incomes are reduced.

In spite of these relationships, levels of adoption of soil conservation technologies are low and political actions to implement programs for improved soil management often remain weak. In part this can be explained by the fact that the introduction of soil conservation technologies normally causes additional costs and the anticipated benefits of the investment only occur after years. On the other hand the impact of soil losses on crop production is very frequently underestimated because productivity decline is not easily detectable from one year to another and might be masked by additional fertilizer input and/or the introduction of new crops or varieties.

Given these circumstances there is a need to determine and better quantify how and to what extent different levels of soil erosion affect productivity and to explore the principal factors involved in the degradation process.

Once this information is available it is possible to calculate erosion induced costs due to yield reductions and/or the increase in fertilizer use and other input requirements. These figures can then be counterbalanced with the costs implied with the introduction of soil conservation and provide a very useful tool to assist political decision making.

In order to obtain these outputs, since 1993 Sorghum, Peanut and Cassava were grown on plots in Santander de Quilichao, employing 3 plots which had been used as standard plots to evaluate the USLE since from 1986 - 1993. The plots suffered different and well documented degrees of erosion and soil degradation. Crop response on these plots is compared with crop performance on plots that had been under improved pasture for more than a decade and also with four plots, where topsoil had been removed artificially by scalping to simulate erosion. Scalping was done to an extent comparable to the soil loss that had naturally occurred on standard plots (i.e. 5, 10 and 13 cm of surface soil). On a fourth plot topsoil was totally removed by scalping 30 cm. Comparison of productivity from naturally eroded plots and scalped plots was incorporated in the trials to examine the assumption made by several researchers, that soil removal is a reasonable simulation of soil loss by erosion.

Moreover erosion treatments were divided in two subtreatments consisting in:
a) complete fertilizer supply and b) no fertilization.

Measurements taken to establish the relationships between erosion, soil degradation and crop productivity comprised:

- Chemical soil analysis: organic matter, pH, total N, different fractions of P (organic P, inorganic P, Bray II-P) K, Ca, Mg, S, Al, Zn, Cu, Mn, B.

- Physical soil analysis: aggregate stability and size distribution, bulk density, pore volume, texture and volumetric moisture content in different soil depths.

- Plant measurements: phenological observations, yield and tissue analysis.

Results from the first two crops have been analyzed and processed to a large extent and show clearly, that loss of topsoil leads to severe yield reductions on these soils.

Sorghum and Peanut yield was strongly correlated to several chemical soil characteristics. Highest correlations were found for organic matter, N, K, inorganic P and aluminum saturation. These parameters were at the same time strongly altered by topsoil loss (Table 2.10).

Table 2.10. Correlations between topsoil removal, sorghum yield and some selected soil characteristics in Santander de Quilichao.

	Topsoil loss	Yield	Organic matter	Total N	Inorg. P	K
Yield	-0.55*	-				
Organic matter	-0.97	0.56	-			
Total N	-0.77	0.71	0.78	-		
Inorg. P	-0.83	0.73	0.88	0.79	-	
K	-0.84	0.77	0.90	0.83	0.97	-
Al-saturation	0.85	-0.77	-0.87	-0.82	-0.96	-0.95

* All correlations are highly significant

Even where the erosion or scalping levels were low, soil amendment, applying lime and fertilizers could not fully compensate topsoil loss (Table 2.11). This underlines the importance of conserving the upper layer of these soils with topsoil depths of only 25-30 cm. Baquero (1993) found similar effects on yield and income on relatively shallow soils in Nariño, South of Colombia.

Data on crop production presented in Table 2.11 also show, that results obtained on the scalping plots are different from those obtained on plots degraded over time where economic yields were consistently lower.

At the current stage of the study the differences between the naturally eroded and the scalped plots are not yet fully understood, but data and soil analysis point to the fact, that this might be due to differences in soil texture caused by different processes of soil loss. As erosion is a selective process, small and light particles are preferentially removed, that is the fine earth fraction and organic matter (Lal, 1987). This could also be shown here, as illustrated by the following equations:

Sand (%) = $102.2 - 1.2 * 10^{-4} x + 1.1 * 10^{-10} x^2$ $r^2 = 0.83$
Silt (%) = $- 7.4 + 1.3 * 10^{-4} x - 1.1 * 10^{-10} x^2$ $r^2 = 0.82$

where X is the amount of topsoil lost (kg/ha)

These equations were obtained on the naturally eroded plots. The increase of the sand content, a fraction with low cation exchange capacity, could partly explain the differences between the scalped and the eroded plots. In the scalping treatments only insignificant changes of soil texture with scalping depth could be observed according to the profile structure.

Table 2.11. Effects of natural erosion and soil removal by scalping on the grain yield of Sorghum and Peanut on an Oxic Dystropet in Santander de Quilichao, Colombia.

		Grain yield in $kg.ha^{-1}$							
		Depth of natural erosion[1]			Depth of soil removed				
Crop	Treatment	5 cm	10 cm	13 cm	5 cm	10 cm	13 cm	30 cm	Control
Sorghum	Without fertilizer	0 e[*]	0 e	0 e	477 a	0 e	0 e	0 e	2124 b
	With fertilizer	164 e	98 e	78 e	2032 b	1076 c	744 cd	0 e	3559 a
Péanut	Without fertilizer	0 i	0 i	0 i	692 f	59 i	4 i	0 i	873 e
	With fertilizer	703 f	385 gh	470 g	2570 a	1611 c	1219 d	275 h	2175 b

* Means followed by the same letter are not significantly different (P = 0,001; Tukey Test)

1 6 years bare fallow

In Figures 2.5. and 2.6. yield losses of Sorghum and Peanut are expressed as a function of cm of topsoil removed. The regression coefficients show a good fit of the regression functions with measured values in the field experiments. Similar functions are also being developed for other soil characteristics and yield response.

These interrelations between soil erosion, soil characteristics and crop production enable to determine the actual productivity status of a soil and to predict the development of productivity with ongoing erosion.

These data illustrate that soil productivity is dramatically affected by erosion. Interestingly Lal (1983) found similar results for maize yields on an Alfisol in Nigeria. Natural erosion reduced maize yield considerably more than the equivalent reduction by artificial desurfacing. In Indonesia, Suwardy & Abujamin (1983, quoted by Stocking, 1984) reported 1200 kg/ha yield loss per cm soil loss on an Oxisol and 1850 kg/ha yield loss per cm soil loss on an Ultisol for maize grown in a rotation. Such losses are considerably greater than losses measured in temperate climates (M.Stocking, 1984). Tropical soils are typically more susceptible to yield declines with erosion. It is to be added that absolute yield losses on tropical soils are doubly serious because of lower initial yields.

2.4. Development of soil conservation effective cropping systems and components.

Rainfall characteristics (amount, erosivity distribution), soil cover and soil physical conditions are the most important factors in determining the magnitude of erosion but they also interfere in the productivity of the cropping systems tested. Annual variations of climate and the position of a cropping system tested in the rotation influence the results, therefore only long term investigation and comparison of results with data from similar trials elsewhere give a reasonable picture of the sometimes complex interactions between cropping systems, soil, climate and productivity of crops. This should be taken into consideration when reading through the following results presented here as year to year data.

The common goal behind all this research is the development of productive, income generating cropping technology, at the same time conserving or even improving the soils as the principal resource base of crop production. Though site specific in nature, deduction of commonalities and principles, applicable to a wider range of situations is also sought for to make work of NGO's and NARS more efficient and to improve potential impact of project work.

The functions of the relations between soil removal and crop yield are shown in the following figures:

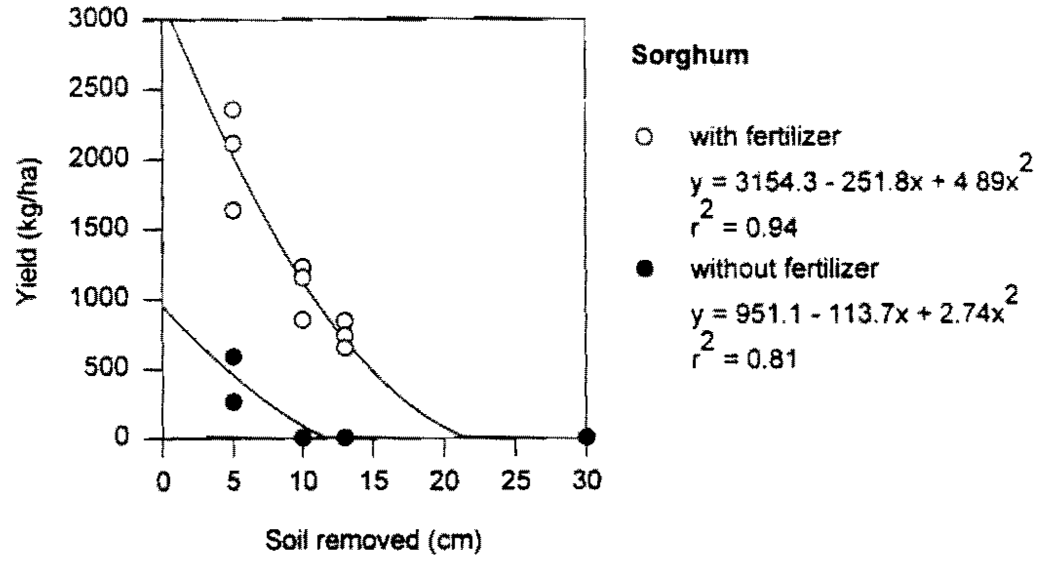


Figure 2.5. Functional relationships between soil removal and Sorghum yields on a fertilized and unfertilized Oxic Dystropept in Santander de Quilichao, Colombia.

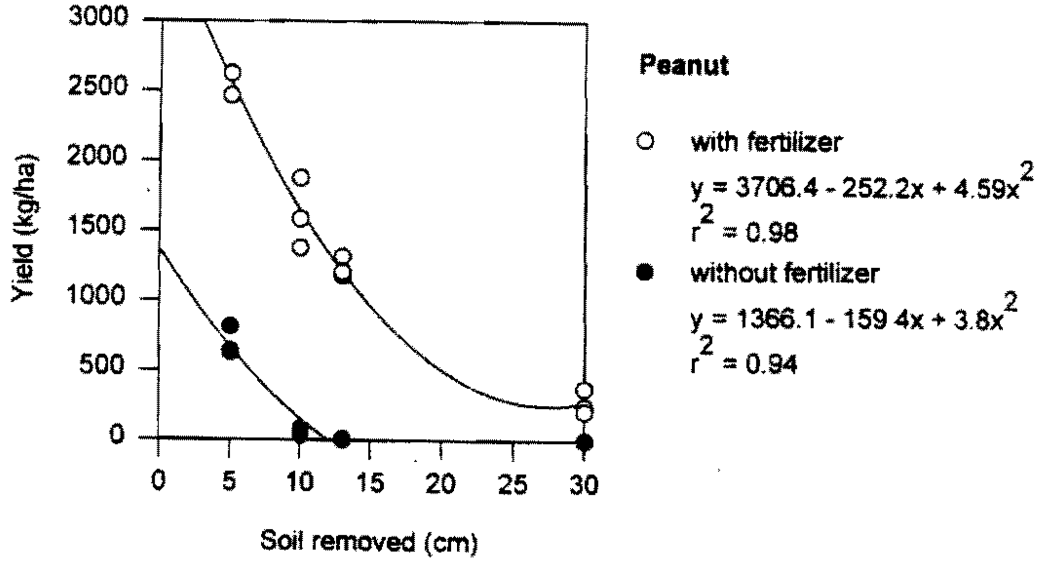


Figure 2.6. Functional relationships between soil removal and Peanut yields on a fertilized and unfertilized Oxic Dystropept in Santander de Quilichao, Colombia.

2.4.1. Soil losses and productivity of cropping systems and rotations.

Work in the first years preceding the project concentrated on the evaluation of tillage practices and its impact on productivity and erosion.

Total annual soil losses as affected by crop management systems are summarized in Table 2.12.

The overall average annual soil losses, soil at this time still showing relatively high stability due to the effects of preceding grassland, from bare fallow plots were > 100 $t.ha^{-1}$ and reached up to 300 $t.ha^{-1}$ in the second year after the start of the experiment on the Mondomo site.

Compared with the traditional cassava cultivation on flat lands growing cassava on contour ridges or with grass strips led to much lower soil losses. On the other hand growing cassava on down slope ridges or in association with early maturing grain legumes resulted in much higher soil losses than the traditional practice (Cassava flat).

Only Cassava/minimum tillage, Cassava on contour ridges and Cassava with grass strips led to soil loss values close to tolerable levels.

Minimum tillage, though effective in controlling erosion led to severe yield reductions in Quilichao due to unfavourable growth conditions for cassava and relatively high weed infestation. From a productivity point of view all other treatments gave also satisfactory yields and therefore might be acceptable to farmers though some of them expressed some concern as regards to potential weed infestation from left grass strips.

Between 1990 and 1992 emphasis was put on the development of soil conserving cassava-forage legume intercropping and its potential to reduce erosion while maintaining soil fertility and crop productivity. Based on earlier results from CIAT (CIAT, 1992) where some solid sown legumes showed good compatibility with cassava, some treatments with undersown legumes were included in the erosion experiments and evaluated over a two year period.

In order to reduce competition, legumes were not solid sown but undersown in double rows along the contour line. Grass barriers with Vetiver grass (*Vetiveria zizanioides*) and Elefant grass were also tested.

As shown in Table 2.13 erosion potential continued to be high in spite of less rainfall in this year and is mainly due to increased erodibility of the soils with prolonged exposure. Cassava as a sole crop again produced erosion above tolerable levels and undersown forage legumes only reduced erosion levels in the second season after its establishment. In the first growing period erosion was even enhanced by legume intercropping because of seedbed preparation, reseeding operations and the human

Table 2.12. Soil losses during 1987-89 cropping seasons at Quilichao and Mondomo (t dry soil/ha) and corresponding cassava fresh root yields in t/ha.

	Santander de Quilichao		Mondomo	
Treatment	Soil losses	Root yield	Soil losses	Root yield
Bare fallow	123	-	178	-
Cassava/Flat	11	31.1	25	19.7
Cassava/Contour-ridges	6.3	29.7	2	15.3
Cassava/Down-slope ridges	49.5	27.7	23.5	15.4
Cassava/Cowpeas	18.5	21.3	33.5	16.8
Cassava/Grass strips	10	27.1	2.3	18.2
Cassava/Min.tillage [1]	2	9.0	2.8	15.7

1) Zone tillage, preparing only the planting holes

Table 2.13. Mean losses of soil dry matter in metric tons, cassava (C) yields (t/ha fresh roots) and forage yields (t DM/ha) of different cassava production systems for Santander de Quilichao and Mondomo [1] (1990/91 - 1991/92).

	Santander de Quilichao			Mondomo		
Treatment *	Soil loss	Cassava yield	Forage	Soil loss	Cassava yield	Forage
1) Bare fallow	152.5	-	-	183.2	14.5	-
2) Cassava with contour ridges	3.0	29.6	-	2.0	15.8	-
3) Traditional (flat)***	7.8	29.2	-	16.4	13.8	-
4) C. with Kudzu/C. macrocarpum [2]	9.7	18.7	2.4	3.2	9.6	3.1
5) C. with Zornia glabra	14.2	19.2	2.9	3.8	13.8	0.6
6) C. with Vetiver barriers**	1.3	26.9	-	2.6	12.8	-
7) C. with Centrosema acutifolium	7.0	21.5	3.5	2.1	12.5	1.9
8) C. with Pennisetum barriers**	3.8	20.0	5.0	0.7	13.4	8.1

* Data of 5 years
** Barriers 8 m apart; Vetiver is not a forage
*** Ploughed, rotavator

1) Mean 10% slope in Quilichao and 15% slope in Mondomo.
2) C. macrocarpum in the cooler climate of Mondomo, Kudzu in Quilichao.

traffic related with these operations and the harvest of legumes. Overall soil cover with undersown legumes due to slow initial development of legumes was not or only slightly higher compared to sole cassava in the first cropping season (data not shown). Compaction of surface soil (more in Quilichao) and less canopy development of intercropped cassava thus led to high erosion in the year of establishment.

In Mondomo erosion levels were low for all cropping systems in the first year because erosive rainstorms were delayed until October. In the second growing season erosion was controlled satisfactorily by undersown legumes, the legumes providing a dense and efficient soil cover from the very beginning of the crop cycle.

Grass barriers and contour ridges led to acceptable soil losses with no yield reductions or even improved yields in the case of cassava on ridges and only slight or moderate yield reductions with Vetiver grass and frequently cut elefant grass (every 2-3 months).

Vetiver barriers occupied 12,5% of the area. They did not affect effective area yield at all and yield reductions by Elefant grass (12% and 5% in both years), occupying 25% of the area were offset by 5 to 8 $t.ha^{-1}$ of forage dry matter.

Summarizing the effects of different cropping systems, it can be concluded that forage legume intercropping was not efficient in controlling soil erosion in the season of establishment. Later on, from the second year on it was effective in checking soil erosion, but cost in terms of yield losses were in the order of 10-20% in the first year and 30-40% in the second year are probably too high to be accepted by farmers, even if they are compensated by forage yields of about 2-4 t of dry matter per hectare.

In this respect grass barriers with cut and carry grasses showed better results and together with the contour ridge-treatment exhibited a good mixture of erosion control and productivity.

Legume intercropping might be an interesting option only, if the cassava crop is used for relay establishment of legumes for subsequent improved pastures or enhanced fallows, thus taking advantage of the often difficult legume establishment over a longer period and enhancing productivity of subsequent rotation elements.

This in mind another two year cropping cycle with modified treatments was started in the 1992/1993 cropping season.

After five years of experiments with cassava cropping systems it was decided to interrupt continuous cassava with contrasting rotation elements. Most of them are commonly known for its potential to restore soil structure and productivity, at the same time being close to common practices in the Andean environment in the Cauca Department.

A more realistic crop rotation (long term experiment) and the immediate and crop rotation effects on soil erosion, soil characteristics and crop productivity were of special interest.

In the Cassava forage-legume treatment which had resulted in relatively high competition and labour constraints when planted row by row, a new strip arrangement of components, maintaining overall plant density, but reducing the interface between legumes and cassava was selected. Performance of this system was compared against continuous traditional cassava, cowpea/beans with organic manure (very widely used by farmers for beans on degraded soils), a legume enhanced fallow after cassava/legume intercropping and newly or relay established grassland as a more intensive form of restoring soil physical properties and correct weed infestation.

Results on soil losses caused by these two year rotation elements and respective figures on productivity are shown in Table 2.14 and 2.15.

Due to low rainfall and relative drought at the beginning of the crop cycles soil losses and crop yields were relatively low.

Compared to cassava, beans and/or cowpea caused only about 30% of soil erosion in this experiment with 4 crop cycles whereas other authors (Howeler, 1985) found higher levels of erosion in these treatments. Rather high weed incidence on these plots after applying chicken manure might have been responsible for this (data not shown).

Erosion in fallow treatments was close to zero and grassland treatments caused erosion only in the first year. Expected differences in soil loss between relay established grass with zone tillage only and newly established grassland with complete tillage did not show up because of lack of erosive rainfalls in the first rainy season.

When comparing plots where grasses were planted into already established legumes against those with legumes sown simultaneously with grasses, the yield of legumes was higher in plots with pre-established legumes, but legume yields decreased in both treatments during subsequent cuttings. Especially in Mondomo, where the cooler climate delayed regrowth and establishment of the legumes, *Brachiaria decumbens* was too aggressive. Less competitive grasses and/or more competitive legumes are needed in order to establish balanced grass/legume mixtures.

Recent experiments with dwarf types of Guinea grass have shown that this might be an option for slightly more fertile soils.

Growing cowpea or beans with hedgerows of Vetiver grass (occupying 12,5% of the effective cropping area) reduced soil losses to tolerable levels. Yet, overall yield of grain legumes was not affected (see also paragraph 2.4.2) corroborating results from earlier years and other experiments executed (see below).

Table 2.14. Mean dry soil losses and respective yields of crops grown in the erosion trial of Santander de Quilichao in 1992/93 and 1993/94. (Values corrected to a 9% slope according to the USLE).

Treatments	Mean soil losses Mg DM/ha	Mean crop yield in Mg DM/ha [1] Main crop	Intercrop/barrier strip
Standard bare fallow plot	139,7	-	-
Continuous sole cassava	12,1	20.29	-
Cassava/legumes [2]	2,2	9.40	2.93
Cowpea sole crop [3]	4,8	0.69	-
Cowpea/*Vetiver* barriers [4]	1,0	0.76	0.67
Grassland/relay establishment	0,8	9.64 [6]	2.50 [6]
Grassland/new establishment	1,8	12.07	0.32
Enriched relay fallow [7]	0,5	-	-

[1] Cassava yield as fresh root weight/ha

[2] Cassava, minimum tillage with row by row intercropping of *Centrosema acutifolium* in the first year and strip cropping of cassava with a legume mixture in the second year, maintaining the same planting density/ha.

[3] Two crops per year fertilized with chicken manure.

[4] *Vetiver* barriers at 8 m distance

[5] Minimum tillage, *Brachiaria* vegetatively interplanted between preestablished legume strips from preceding cassava intercrop; in newly established grassland soil was tilled and legume and grass planted simultaneously.

[6] *Brachiaria decumbens* and *Pueraria phaseoloides*.

[7] Previous cassava crops were undersown with *Zornia glabra* which was left after harvesting cassava.

Table 2.15. Mean dry soil losses and respective yields of crops grown in the erosion trial of Mondomo in 1992/1993 and 1993/1994 (values corrected to a 9% slope according to the USLE) [8]

		Mean crop yield in Mg DM/ha [1]	
Treatments	Mean soil losses Mg DM/ha	Main crop	Intercrop/barrier strip
Standard bare fallow plot	130.3	-	-
Continuous cassava sole	11.7	8.00	-
Cassava/legumes [2]	3.6	3.08	1.58
Beans, sole crop [3]	3.0	0.64	-
Beans/*Vetiver* barriers [4]	0.6	0.57	0.79
Grassland/relay establishment [5]	0.4	10.84 [6]	3.31
Grassland/new establishment [5]	0.5	12.11	1.33
Enriched relay fallow [7]	0.3	-	-

1) Cassava yield as fresh root weight/ha

2) Cassava, minimum tillage with row by row intercropping of *Centrosema acutifolium* in the first year and strip cropping of cassava with a legume mixture in the second year, maintaining the same planting density/ha.

3) Two crops per year fertilized with chicken manure.

4) *Vetiver* barriers at 8 m distance

5) Minimum tillage, *Brachiaria* vegetatively interplanted between preestablished legume strips from preceding cassava intercrop; in newly established grassland soil was tilled and legume and grass planted simultaneously.

6) *Brachiaria decumbens* and *Centrosema macrocarpum*.

7) Previous cassava crops were undersown with *Zornia glabra* which was left after harvesting cassava.

8) Real soil loss on this 13-20% slopes was two to three fold the value of the standardized 9% slope figure.

As already mentioned, rotation elements were also introduced to look at crop rotation effects, related with different treatments. In order to be able to evaluate residual effects, a single crop, cassava was selected for the subsequent season 1994/1995 on all plots.

Nevertheless, some continuous long term patterns of differential cropping practices were maintained:

- Continuous cassava, tilled
- Crops + Vetiver hedgerow, tilled
- Crops + reduced tillage
- Crops + legume component

On the basis of this continuous patterns of land management, comparisons of traditional land use versus intensified land use practices could be made as regards to sustainability.

Cassava after two years of short term grain legumes with chicken manure could be compared with the same treatment plus barrier or with continuous cassava.

Performance of a cassava crop after 2 years of managed grassland could be compared against crop performance after two years of natural weed fallow - a practice of less utility but traditionally used by farmers.

Finally cassava after grassland tilled against cassava after grassland with herbicide and minimum tillage or continuous cassava with tillage.

Preliminary results from the first harvest in 1995 in Quilichao are shown in Table 2.16.

First of all it can be stated that with the exception of continuous cassava all treatments presented low to very low soil losses, which means they were sustainable from a soil conservation point of view.

Residual effects leading to less erosion were obtained by organic manures (Treatment 2), two year fallow, and even better by two years of grassland with legumes. Effects of the last two treatments were comparable to the effect of a dense Vetiver barrier. The sequence of reduction in soil losses measured on plots compared very well with results from analysis of aggregate stability on this plots in the course of this year (See Table in paragraph 2.2.3.).

Table 2.16. Preliminary results of average dry soil loss (t/ha). Root yield (t/ha fresh cassava) and production of forages (t/ha dry matter) in different production systems in Santander de Quilichao (1994-1995). Evaluation of residual effects of cassava crop rotation 1992-1994.

		Cassava crop			
Treat No.	Previous crops period 1992-1994	Period 1994-1995	Topsoil loss t/ha (5)	Forage t/ha DM (5)	Cassava yield * t/ha (5)
1	Bare plot (USLE)	Bare plot (USLE)	127.50		-
2	Cowpea Monocult. (1)	Cassava (1)	1.71		30.10
3	Trad. Cassava	Cassava (2)	5.15		16.93
4	Brachiaria + Kudzu (M)	Cassava (M)	0.55		26.38
5	Fallow	Cassava	0.84		20.63
6	Cowpea + Vetiver	Cass+Vetiver (1)(2)(3)	0.59	4.98 (6)	18.68
7	Cassava + leg. strips	Cass+Leg. strips (4)	1.53	6.8 (7)	7.28
8	Kudzu + Brachiaria	Cassava-tilled	0.60		26.73

* CM 2136-2

(1) Fertilized with 2 t/ha chicken manure per crop cycle, all other treatments received mineral fertilizer.
(2) 10.000 pl/ha.
(3) Barriers 8 m apart
(4) Legume strips of 1.5 m width, 2.5 m distance
(5) Period: 1994-1995 (10 months)
(M) Minimum tillage, planting spots
(6) Source of mulch
(7) Centrosema m. 5.76 t/ha DM
Galactia s. 0.87 t/ha DM
Chamaecrista r. 0.16 t/ha DM

New arrangement of forage legumes in strips with cassava (1,5 m legumes, 2,5 m cassava) led to a completely different response as it was intended. Competition effects on cassava increased dramatically. A reason for this might be, that the legume strip received full sunlight during the whole cropping period - even in the dry season. This led to a duplication of legume forage yields but reduced cassava yield to 25 to 30% of the control. Strips with legume mixtures thus are not applicable in this way but only as wider strips in a type of contour rotations. Farmers first were very exited from the new strip arrangement because of year round easy access to fodder plants, but changed their opinion when competition effects became evident.

Highest cassava yields were obtained after grain legumes with chicken manure, followed by the two year grass/legume rotation elements, enhanced natural fallow, Vetiver, and continuous cassava.

Both of the last two treatments suffered to some degree from root rots which might be attributable to the prolonged cassava cultivation.

The results obtained with a grass legume rotation against bush/weed fallow to restore soil structure and fertility and with organic manuring against mineral fertilizers alone match the dual objective formulated for agricultural research: "Increase food production while conserving or enhancing the natural resource base"[1]. Productivity of land could be increased, at the same time reducing soil erosion to tolerable levels. In 1995/96 the same treatments will be continued with maize as the principal crop and *Chamaecrista rotundifolia* as legume component.

2.4.2. Development of productive cropping systems with undersown legumes.

Permanent ground cover with forage legumes is one of many crop management systems favoured for soil conservation and for improving soil fertility in the humid tropics. As cassava farmers rarely apply chemical fertilizers, forage legumes in association with cassava might be viewed as an alternative "biological source" for soil improvement.

Results from research on erosion measurement plots consistently demonstrated that undersowing of legumes can reduce erosion in cassava to acceptable levels once the legumes are well established.

Nevertheless competition levels in tested cassava/legume systems were high and constitute a constraint for the adoption of intercropping systems. Therefore, parallel to the work on erosion plots, agronomic research on improving these systems was carried out throughout the last years with the overall goal of reducing soil erosion, at the same time minimizing yield losses of cassava. In order to obtain results satisfying this dual objective several strategies were under investigation:

- identification of less competitive legume species and/or more tolerant cassava ecotypes.
- changing the arrangement and composition of the components
- identify morphological and physiological traits that influence the magnitude of competition and
- feasibility of legume systems from a farmers point of view including improved management practices.

Based on the observations of high competition with solid sown or double row planted legumes in cassava and on the identification of new promising species with good soil

[1] M. Bohnet, cited in ATSAF - Circular 42/95, p.34.

cover capacity and adaptation to infertile acid soils a large field experiment was initiated. In this trial single row intercropping without extraction of the legumes, after they were cut was tested. Also different plant densities and varieties were applied.

From results shown in Table 2.17 and 2.18 it can be concluded that competition exercised by undersown legumes with these changes could not overcome the problems already identified in previous trials.

No major differences due to cassava density could be observed but legume dry matter production was inversely correlated with cassava yield ($r = 0,56$; $p = 0.05$) and minor differences could also be observed with respect to varietal tolerance to intercropping, more leafy and low branching types suffering slightly less from competition.

Legumes providing sufficient soil cover caused yield losses in the order of 20-25% in the first year and 40-50% in the second growing season. About half of the yield losses in the second season could be attributed to the legumes itself and the other 25% to reduced zone tillage for cassava (data not shown).

However, there were differences between legumes, some of them being more competitive than others. From observations of the root system of *Galactia striata* (very extensive, grasslike and profuse), which consistently exercised highest competition, it was concluded that root characteristics might play a major role for selecting low competitive cover legumes.

Based on this observation and the hypothesis that above ground competition with low growing perennial forage legumes is of minor importance in these systems, a further attempt to explore the interactions below ground was undertaken.

Two out of seven cassava/legume systems tested in the long term agronomic intercropping trial were selected for direct root observation on soil profiles of 1 m width and 90 cm depth in the second year after establishment. Cassava was about 6 months old at this point in time.

Counts of root tips per cm^2 were digitized and fed into a computer program.

Compared cassava alone (Fig. 2.7) with highest root densities of about 0,5-0,6 roots per cm^2 (R cm^2) the introduction of *Centrosema acutifolium* (CIAT No. 5277) to the system led to higher root densities and deeper root extension (Fig. 2.8).

Highest root densities however were obtained by combining cassava with *Zornia glabra* (CIAT No. 8283) as it is shown in Figure 2.9.

Table 2.17 Total fresh root yield of cassava (t/ha) when grown simultaneously with legumes in Santander de Quilichao in the first and second cropping cycle. [1]

Treatment (intercropped legumes)	Cassava yield first season [2]	% of control	Cassava yield second season [3]	% of control
A) Legumes				
. Cassava alone (control)	37.6 ± 1.6[4]	100	32.40 ± 2.4	100
Beans/cowpea [5]	37 4 ± 1.3	99	28.66 ± 1.7	88
. Galactia striata	25.1 ± 2.0	67	14.18 ± 1.4	43
. Macroptilium gracilis [6]	31.3 ± 2.0	83	20.82 ± 1 6	64
. Zornia glabra	27.3 ± 1.9	72	17.55 ± 1.3	54
. Zornia latifolia	33.9 ± 2.3	90	23.64 ± 0.9	73
. C. acutifolium	26.8 ± 2.5	71	17.19 ± 1.3	53
. Stylosanthes capitata	28.3 ± 1.6	75	15.36 ± 1.1	47
. Arachis pintoi	31.2 ± 2.3	83	22.12 ± 1.3	68
B) Planting density				
10.000/ha	31.3 ± 0.9	-	20.55 ± 0.9	-
15.000/ha	30.7 ± 1.2	-	22.11 ± 1.1	-
C) Variety of cassava				
M Col 1684/CM 849-1	30.9 ± 1.1	-	24.59 ± 1.1	-
M Col 1522/CM 523-7	31.0 ± 0.9	-	18.06 ± 0.6	-

[1] One row sown between cassava rows spaced at one meter

[2] All plots tilled with cultivator

[3] Only control and Cowpea tilled; all other plots reduced tillage of planting holes with a hoe

[4] Se: standard error of the mean

[5] In the second season cowpea

[6] In the second season replaced by Stylosanthes guianensis

Table 2.18. Cassava yields in the second cropping cycle as affected by interrow cover crops, planting density and variety of cassava in Santander de Quilichao on an isohyperthermic Dystropept.

Treatments	Cassava yield t fresh roots/ha	% of best treatment	Legume yield t DM/HA	Mean % Soil cover [5]
a) Intercrop				
Cassava sole crop	32.40 a [3]	100	-	-
C. + Cowpea	28.66 b	88	n.d.	6.5
C. + Zornia latifolia [1]	23.50 c	73	0.557 a	12.5
C. + Arachis pintoi [1 4]	22.10 c	68	n.d.	13.2
C. + Stylo guianensis [1 2]	20.82 cd	64	2.268 b	10.9
C. + Zornia glabra [1]	18.03 de	56	4.401 d	23.0
C. + Centrosema acutifolium [1]	17.19 ef	53	3.377 c	23.2
C. + Stylo capitata [1]	15.36 ef	47	3.026 bc	21.3
C. + Galactia striata [1]	14.18 f	44	4.183 d	25.7
b) Planting density				
10.000 pl/ha	20.55 a	93	3.232 a	17.3
15.000 pl/ha	22.10 a	100	2.785 a	16.8
c) Variety				
CM 849-1	24.61 a	100	2.894 a	17.1
CM 523-7	17.95 b	73	3.128 a	16.9

[1] Minimum tillage, only loosening of soil at the planting site with a hoe.

[2] Newly established after Macroptilium gracilis in the first cropping cycle.

[3] Data followed by the same letter are statistically not different at the $\alpha = 0.05$ level DUNCAN-grouping

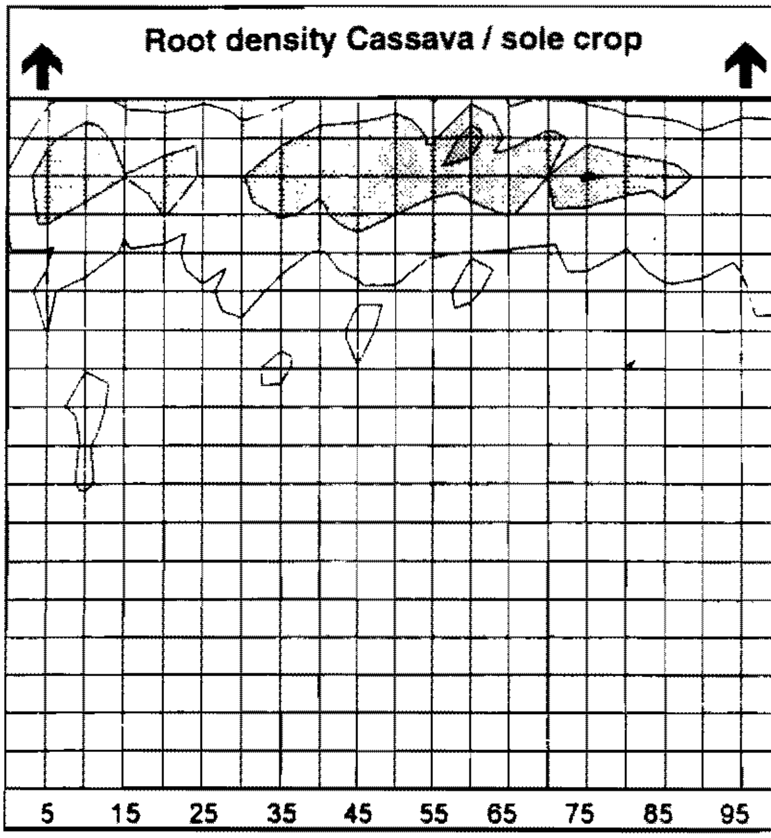
[4] Not harvested

[5] Whole cropping cycle, legumes were cut several times

Total number of roots in the profile (0,9 x 1 m) were 1696, 3060 and 6376 for cassava alone, Cassava/Centrosema and Cassava/Zornia respectively with major differences in the 20-40 cm horizon.

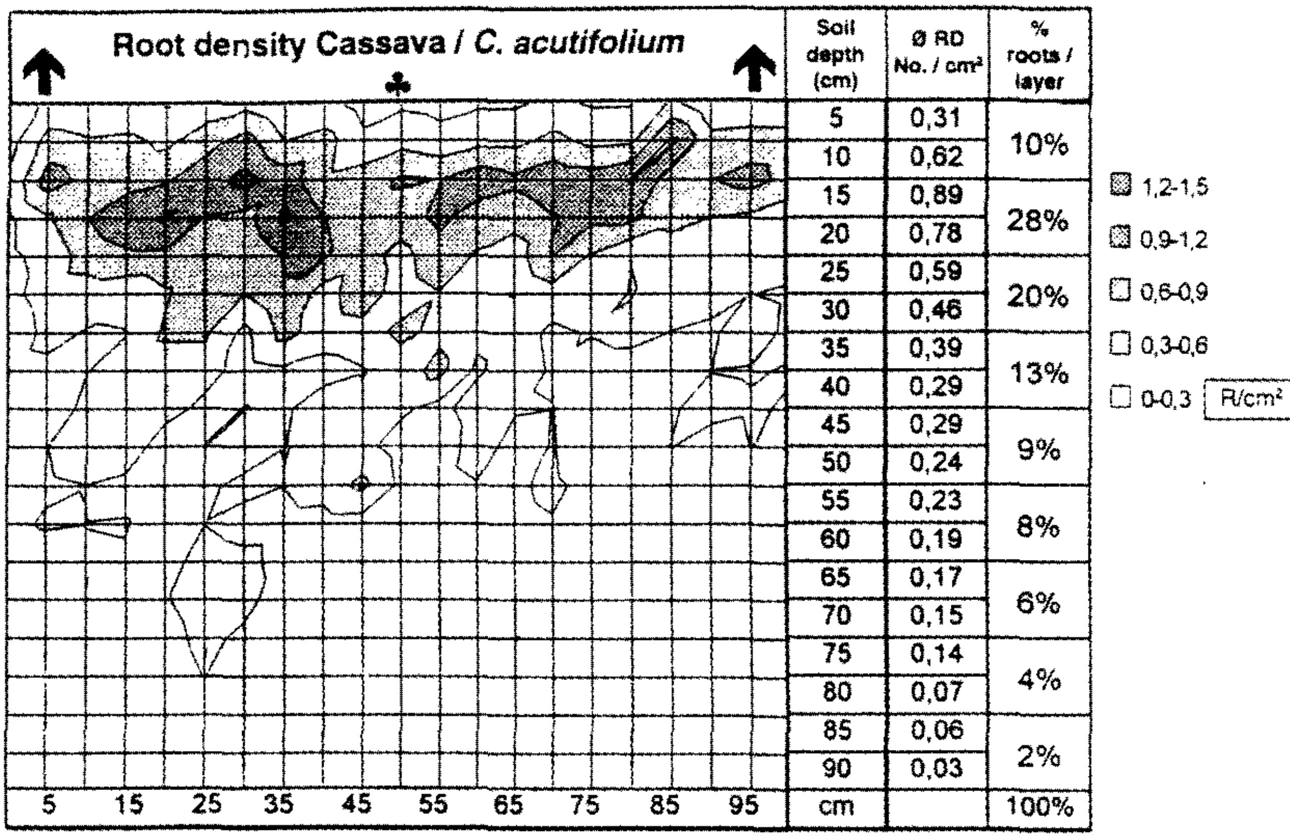
Highest root densities were obtained by combining cassava with *Zornia glabra* (CIAT No. 8283). Most intensive root growth with root densities of 1,6-2,1 roots per cm^2 occurred between 10-15 cm of soil depth. Overall root densities with Zornia were three to four fold of what could be found in the sole cassava system and nearly two times as much as with *C. acutifolium*. 74% of roots were concentrated in the 0-30 cm horizon and 96% of the roots in the 0-60 cm horizon. Nevertheless, because of higher absolute values there were still nearly as much roots in the lower profile as with *Centrosema acutifolium* (Fig. 2.8).

Corresponding yield data from cassava and the legumes showed a clear yield decrease of cassava in response to the legume intercrops. There were yet no significant differences between competition from Centrosema and Zornia. Higher root density and biomass production with the Zornia treatment in this case did not cause lesser cassava



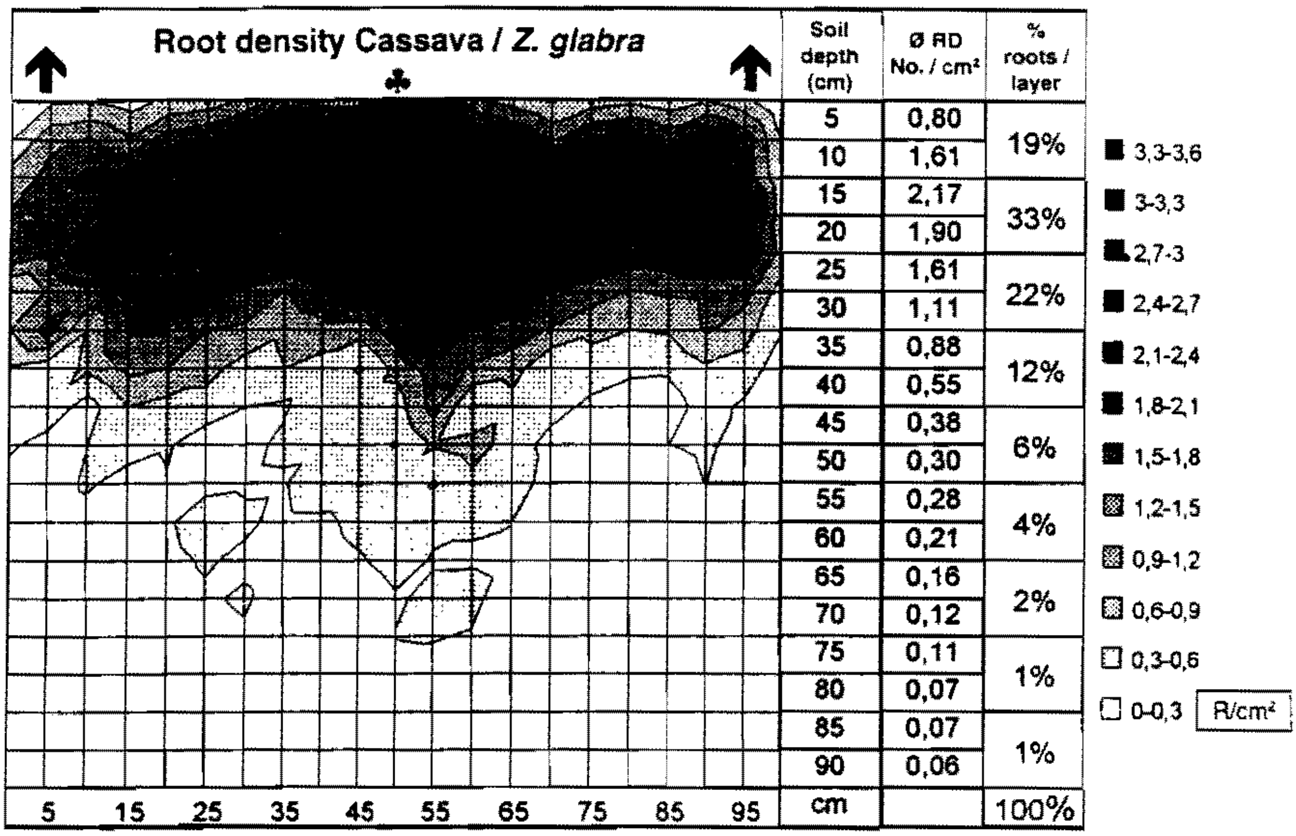
Soil depth (cm)	Ø RD No. / cm²	% roots / layer
5	0,26	24%
10	0,53	
15	0,68	35%
20	0,51	
25	0,34	18%
30	0,22	
35	0,22	12%
40	0,19	
45	0,15	7%
50	0,10	
55	0,07	3%
60	0,03	
65	0,02	1%
70	0,01	
75	0	0%
80	0,01	
85	0,01	0%
90	0	
cm		100%

Figure 2.7. Root densities (RD) in number of roots per cm² and root distribution in different soil layers of cassaa (CM 849-1) in a natural soil profile (Mean of three replications). † = Cassava plant barriers; ♣ = legume row.



Soil depth (cm)	Ø RD No. / cm²	% roots / layer
5	0,31	10%
10	0,62	
15	0,89	28%
20	0,78	
25	0,59	20%
30	0,46	
35	0,39	13%
40	0,29	
45	0,29	9%
50	0,24	
55	0,23	8%
60	0,19	
65	0,17	6%
70	0,15	
75	0,14	4%
80	0,07	
85	0,06	2%
90	0,03	
cm		100%

Figure 2.8. Root densities (RD) in number of roots per cm² and root distribution in different soil layers of a mixed cropping systems of cassava (CM 849-1) with *Centrosema acutifolium* (CIAT No. 5277) in natural soil profile in Santander de Quilichao. (Mean of three replications). ↑ = Cassava plant; ♣ = Centrosema.



Soil depth (cm)	Ø RD No. / cm²	% roots / layer
5	0,80	19%
10	1,61	
15	2,17	33%
20	1,90	
25	1,61	22%
30	1,11	
35	0,88	12%
40	0,55	
45	0,38	6%
50	0,30	
55	0,28	4%
60	0,21	
65	0,16	2%
70	0,12	
75	0,11	1%
80	0,07	
85	0,07	1%
90	0,06	
cm		100%

Figure 2.9. Root densities (RD) in number of roots per cm² and root distribution in different soil layers of a mixed cropping system of cassava (CM 849) with *Zornia glabra* (CIAT 8283) in a natural soil profile in Santander de Quilichao. (Mean of three replications). ↑ = Cassava; ♣ = Zornia.

yield and only slightly affected the shoot biomass.

From this trial it may not be concluded that higher root biomass and root intermixing with legumes or legume types with higher root density are always or necessarily leading to more competition because *Centrosema acutifolium* with a less intensive and more evenly distributed root system was causing the same levels of competition as *Zornia glabra*.

It can be concluded that other attributes like response to waterstress, partial shading and other physiological traits also play a major role and need to be looked at in more detail.

Screening of low competing, fast covering forage legumes was continued throughout the last years, taking into account progress made in the area of agronomy and farmers reactions to new components under investigation. For this purpose plants were sown simultaneously with cassava and performance of both components evaluated.

Table 2.19. summarizes some of the most promising results of this activity including useful graminea with potential as temporary, sown barriers or for *in situ* mulch production.

Though the legumes could not compete with grass like species like *Pennisetum glaucum* nine out of 22 tested legumes developed quite fast, *Chamaecrista rotundifolia* exhibiting outstanding soil cover capacity already two months after sowing. Biomass production was lower than that of grasses but *C. rotundifolia*, which provided a dense soil cover during the whole crop period, produced the highest biomass (4,5 t DM).

Most surprisingly this did not lead to yield reductions when compared with legumes like *Chamaecrista kunthiana*, producing only 0,3 t DM·ha^{-1}.

So far little is known about the reasons for this outstanding performance. A deep but tiny root system, low nutrient requirements, immediate physiological response to water stress and economic use of water are amongst some of the traits identified in preliminary studies.

Based on the extraordinary good results obtained with *Chamaecrista rotundifolia* (CIAT No. 8590) in the screening trials and the excellent characteristics of this plant (low growing, not winding, early vigor, abundant seed production, resistance to pests and diseases, forage value) a regular field trial was planted in 1994.

Chamaecrista was sown every 25 cm at a row distance of one meter between cassava. It established quickly (Table 2.20) and after four month abundant seed could be harvested (21,5 kg·ha^{-1} equivalent to 800 seeds per linear meter).

Table 2.19. Results from a screening trial to identify intercrops with potential for soil conservation in cassava cropping systems (Mean of two replications). Santander de Quilichao, 1992-1993. Results from 9 out of 22 species tested. Cassava variety CM 2136-2.

Plant species intercropped	CIAT No. of Accession	% soil cover 2 MAP		Intercrop yield t DM.ha^{-1} [2]		Fresh root yield of cassava in t.ha^{-1}	
Legumes:							
Chamaecrista kunthiana	20778	12	N.D. [1]	0.344	(0.06)	36.92	(2.6)
Aeschinomene brasiliana	9046 [3]	15	-	2.700	-	-	-
Centrosema acutifolium	5277	16	(3.9)	1.737	(0.03)	38.93	(4.6)
Crotalaria juncea	21709	24	(5.9)	n.d.		34.79	(5.5)
Chamaecrista rotundifolia	8990	35	(9.9)	4.550	(1.8)	36.04	(3.9)
Pearl Millet:							
Pennisetum glaucum [4]							
No. 1 (variety)		75	(4.9)	4.175	(0.31)	23.33	(5.4)
No. 2 (hybrid)		75	(4.9)	3.040	(0.31)	29.68	(10.2)
No. 3 (hybrid)		80	(5.6)	3.310	(0.48)	27.77	(1.2)
No. 4 (hybrid)		80	(0)	5.075	(0.26)	15.55	(5.7)

[1] Standard error

[2] For Pearl Millet forage determined 2 MAP, all other legumes after cassava harvest 11 MAP

[3] One replication only

[4] Unreleased material from INTSORMIL

Table 2.20. Results from growing cassava with and without Chamaecrista rotundifolia (CIAT No. 8990) as an undersown legume cover crop [1)] in Santander de Quilichao [2)].

	% soil cover of legume					
	1 MAP	2 MAP	3 MAP	Legume yield t DM 11 MAP	Cassava root yield [3)] t/ha	Harvest index (fresh wight)
Cassava sole crop	-	-	-	-	20,54 a (100%)	0.60 a
Cassava plus Chamaecrista	1,63	22,87	67,5	8,203	15,92 b (77,5%)	0.59 a

1) Sown in a single row between cassava (1,0 x 0,25 m)

2) Because of total defoliation of cassava by CBB between July to September, undersown legume was completely exposed to sunlight and competition strongly increased compared to normal conditions.

3) Newman Keuls test, $\alpha = 0,05$

Contrary to the screening trial, the trial at larger plots (25 m^2 plots with eight replications) was disturbed by Cassava Bacterial Blight (CBB) at the end of the first rainy season. The variety grown (CM 523-7) tolerated the disease, but cassava was nearly completely defoliated and canopy recovered only two months later. Under this circumstances growth and development of the undersown legume was very abundant. Thus, competition during the dry season was strongly increased and led to a yield reduction of about 20%, which was much less than could have been expected according to experiences with other legumes in a similar situation.

Ease of harvest, an important criteria for farmers, was favoured by undersown *Chamaecrista* but incidence of the burrowing bug (*Cyrtomenus bergi*) was significantly higher with the soil cover, an issue that needs further monitoring in areas where this pest can cause economic yield losses.

A wider set of adequate low competing legumes for different altitudes, an adequate and cheap sowing equipment for small seeded legumes with no or only rough soil preparation and further development of the technology with farmers need major attention to make these technologies work.

Morphological and physiological characterization of *Chamaecrista* and similar legumes is needed to support this process with efficiently selected, adequate germplasm.

2.4.3. Development of hedgerow components to reduce slope length.

Research on erosion plots during the last years has consistently demonstrated that densely planted grass barriers at 8-10 m distance are highly recommendable to control erosion and achieve acceptable yields on slopes of 5-20% (Ruppenthal, 1994).

Erosion research with shrubby components was not yet executed but *Cratylia argentea* and *Flemingia macrophylla* could be identified as highly promising species with good persistence and tolerance to frequent cutting. Erect, unbranched growth types of *Flemingia* showed the most promising features as single row shrub. *Cratylia* seems to be adequate for wider strips or strip rotation on altitudes below 1300 ma.s.l.

With respect to grass barriers, several grasses with good adaptation to acid low-P soils could be identified. Besides Imperial grass (*Axonopus scoparius*) already used to some extent in the project region these were Elefant grass (*Pennisetum purpureum*), Citronella (*Cymbopogon nardus*), Vetiver (*Vetiveria zizanioides*), Guatemala grass (*Tripsacum andersonii*), Partiña grass (*Andropogon leucostachyus*) and on slightly better soils Lemon grass (*Cymbopogon citratus*). Also Dwarf Elefant grass (*P. purpureum* cv. Mott) performed surprisingly well. Because of higher palatability, convenience of harvest at lower growth height compared to normal Elefant grass it is now widely requested by farmers and local organizations as sole and barrier crop.

Transplanting trials for evaluation of establishment percentage (data not shown) gave best results for Cymbopogon species followed by Vetiver and Guatemala grass. Establishment of Imperial grass as a barrier requires double or triple rows to obtain sufficiently productive and dense barriers.

On farm trials on seedling storage of vegetative planting material were executed together with CVC and FIDAR in the Mondomo area. It could be shown that proper storage of plantlets in small heaps under a tree for three and ten days before planting the barriers did not affect establishment and early development of the grasses tested. In the rainy season mean percentage of establishment 30 days after planting was 93, 97 and 99% for Vetiver, Lemon grass and Citronella respectively. The data confirm earlier findings with somehow lower establishment rates and show that storage of plantlets did not affect the material, thus facilitating logistics of harvest transport and distribution to farmers.

Further agronomic trials on effects of planting density and soil amendment are in the process of evaluation as well as data collection on barrier productivity on farmers fields in the northern Cauca Department.

Development of recommendations for management and species selection for improving performance and farmer adoption are the objectives behind these activities.

Besides the fact that barriers occupy part of the field, they also need to be planted, require maintenance and often cause competition to crops grown between the barriers. In order to overcome these adoption constraints, they have to be minimized and/or the value of the barriers has to be increased to become as attractive as the crop itself.

Besides growth, height and biomass production, competition of grass barriers is largely determined by interactions below ground, an area that is poorly understood so far.

In order to get a better understanding of the nature and importance of below ground interactions, a trial was set up, growing cassava alone and along barriers of different grasses at a distance of only 0,55 m. Root observation piths were established at the ends of cassava/grass plots.

As shown in Figures 2.10, 2.11 and 2.12 the three grasses tested, developed a quite distinct rooting pattern, Vetiver intermixing little with cassava roots and showing a vertical downward growth with little branching. By contrast, the profuse vertical and horizontal spread of Guatemala grass and cassava roots suggested a joint exploitation of soil volumes by the two species, Guatemala restricting cassava root growth in the upper horizon. Lemon grass showed an intermediate pattern but allowed better root development of cassava in the upper, fertile soil horizon. Vetiver grass reached a total root length of 7 m within 0,4 - 0,6 m width on each side of the grass barrier, allowing cassava roots to expand and reach 17 m total root length in the same 20 week period.

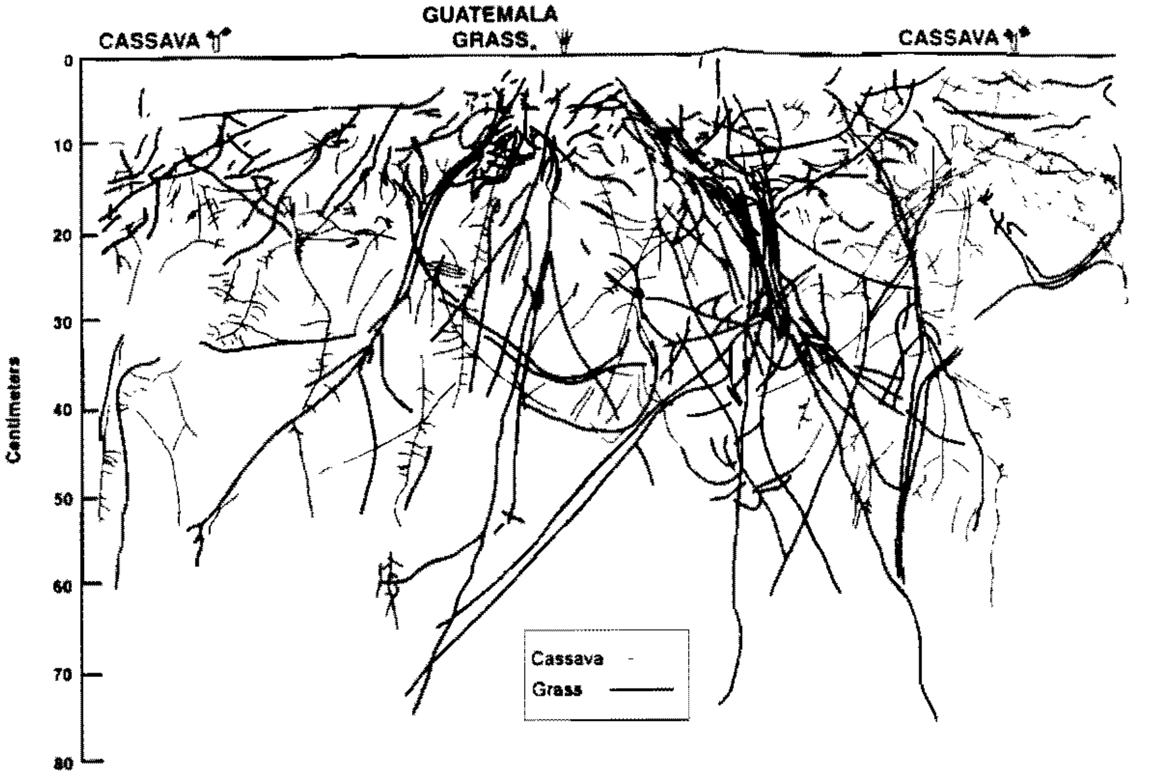


Fig. 2.10. Rooting patterns of cassava with Guatemala grass grown as barrier in association with cassava (M Col 1505) on an Oxic Dystropept in Santander de Quilichao.

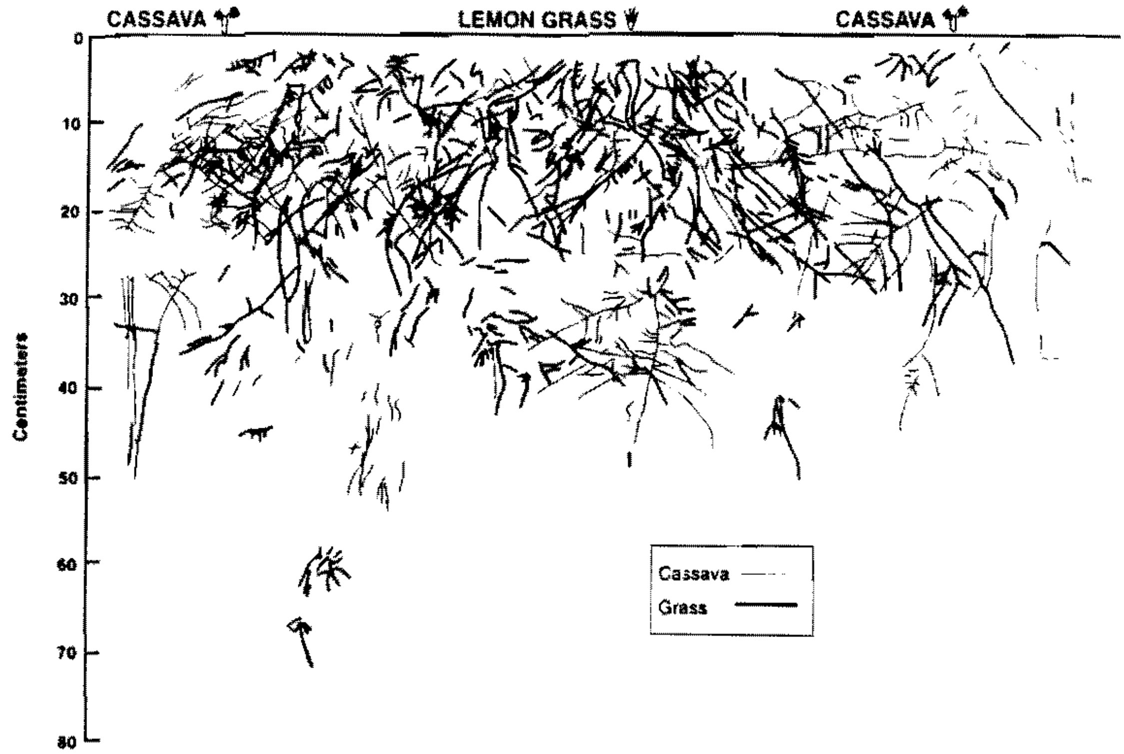


Fig. 2.11. Rooting patterns of cassava with Lemon-grass grown as barrier in association with cassava (M Col 1505) on an Oxic Dystropept in Santander de Quilichao.

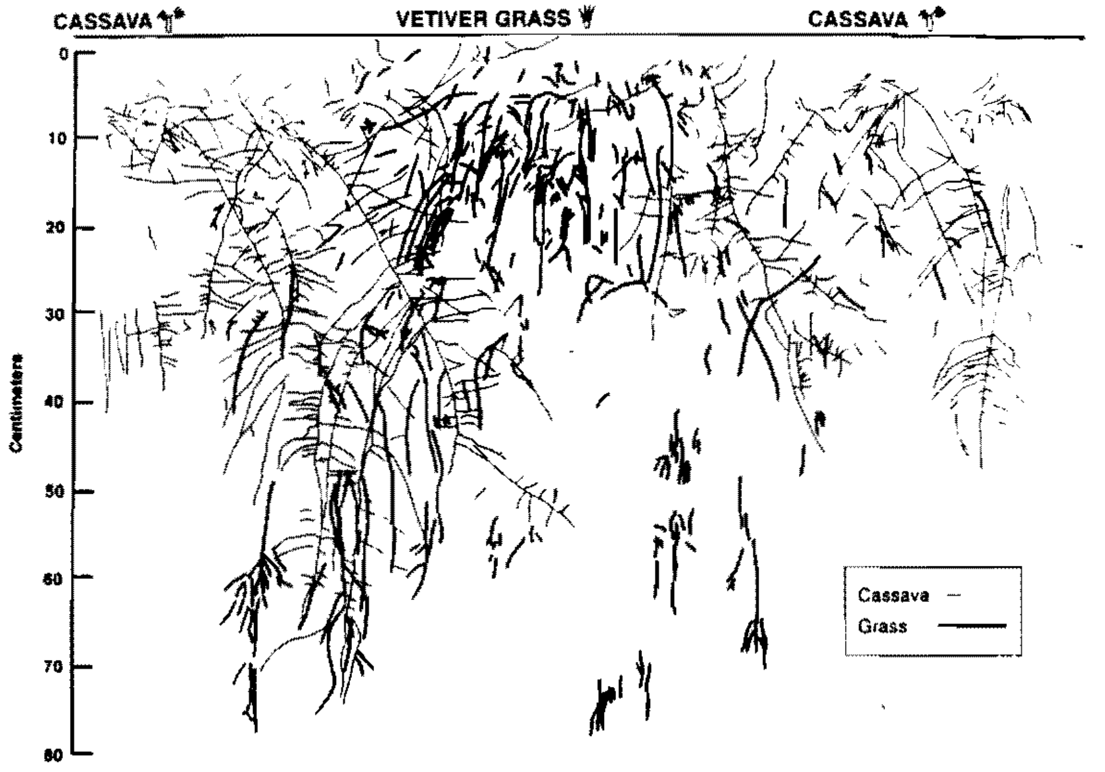


Fig. 2.12. Rooting patterns of cassava with Vetiver grass grown as barrier in association with cassava (M Col 1505) on an Oxic Dystropept in Santander de Quilichao.

Guatemala grass and lemon grass reached root lengths of 16 m, at the same time restricting cassava root lengths to about 10 m.

Given this distinction in rooting patterns and spatial root distribution and taking into account the marked differences between grasses in growth and biomass production, it can be assumed that cassava yields have to respond to these differences.

There was little or no barrier effect on height of cassava but cassava root yield was only 1240, 1210 and 513 g per plant in the presence of barriers, compared to 2194, 1691 and 1350 g per plant in the plots were Vetiver grass, Lemon grass and Guatemala grass had been removed, still exercising some residual effects.

Grasses like Vetiver with moderate growth and Lemon grass which grew slowest and produced the least biomass, had less impact on root yield because of spatial differentiation in the main rooting zone and because of free intermix of roots. Guatemala on the other hand competed very strong because of intensive root competition and high biomass production and therefore should not be used as a barrier in cropped fields but for productive stabilization of road ditches with poor soils.

Weakly competing barrier plants with interaction mainly below ground e.g. with dense and solid, but non competing root systems are recommended for cassava in hillsides. Barriers differing from this plant type must have an attractive paying off to farmers in the form of forage or other byproducts compensating for potentially high yield losses and the labour involved in managing the barrier strips.

Vetiver grass, though not producing forage, but highly valuable as a source of slowly decomposing mulch material and low in maintenance requirements has very favourable characteristics in this respect.

The high efficiency in retaining soil and water runoff sometimes can even enhance crop production on hillsides, thus also creating some short term benefit to the farmers.

Growing cowpea as a sole crop and with Vetiver barriers, 8 m apart in Santander de Quilichao led to a considerable yield reduction of the first row adjacent to live barriers (Fig. 2.13) in the barrier treatment.

Yet, overall yield per plot was higher for cowpea, as rows downslope of the barrier yielded more than in the control without barrier. This confirms earlier observations from Vetiver, grown with cassava in the preceding cropping cycle and it may be speculated, that higher water infiltration at the barrier and subsequent improvement of water availability on the lower side of the barrier caused by interflow led to this overcompensation.

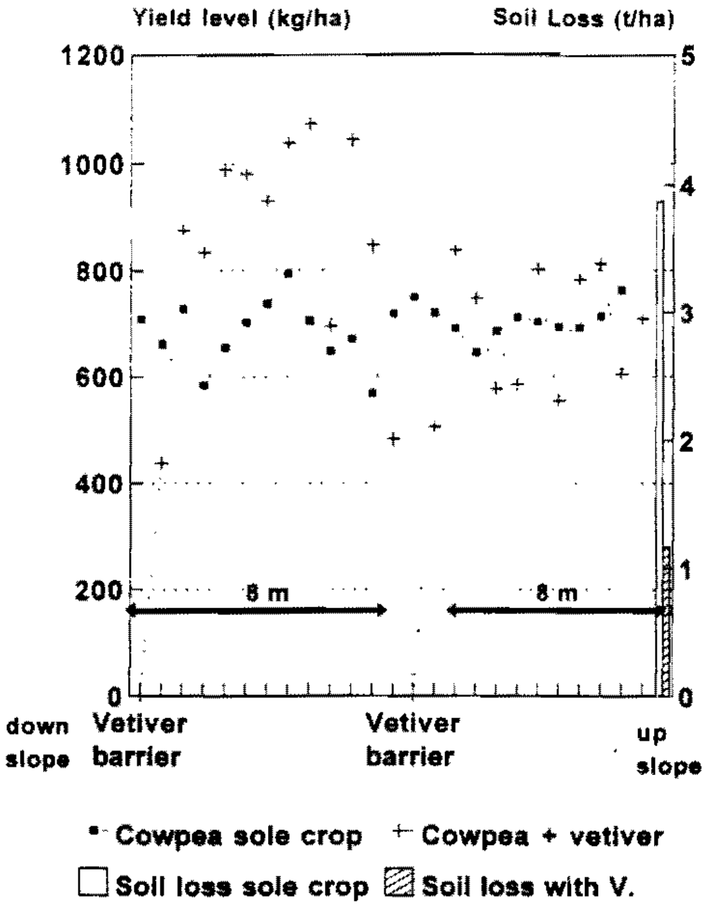


Figure 2.13. Row by row yield level of cowpea (kg/ha) when grown as a sole crop or when grown with grass barriers of Vetiveria zizanioides on a 10% slope in Santander de Quilichao. Mean of two successive crops.

Further research on the aspects of water use and hydrological aspects related to conservation components is suggested for improved water use and management in hillsides.

A different approach, strategic in the sense of identifying local opportunities for aggregating value to a conservation component and quite site specific from a technical and socioeconomic point of view, was chosen in collaboration with a farmer community in the remote area of Buenos Aires/Cauca.

In this area, farmers use to browse bush fallow land and degraded pastures to collect Partiña grass (probably Andopogon leucostachyus) which then is dried, selected and sold to clients from broom factories as a raw material.

By uprooting the grass and planting it in barrier rows, it could be shown that it is easy to transplant and has potential for use as a barrier for erosion control, at the same time producing some economic benefit. After one year of farm experimentation it was found, that it needs double row planting and denser spacing to fulfil the function of erosion control within a reasonable time. The functional properties can be further enhanced by combining the two rows with creeping, relatively shade tolerant forage peanut (Arachis pintoi), which at the same time fixes nitrogen and controls weed growth between the grass rows after they are cut.

This system illustrated in Figure 2.14 is now under evaluation and a project for a small broom manufacturing unit is formulated together with CETEC, and NGO collaborating in this activity.

The effectiveness of barrier components to control erosion is known - overcoming the technical and socioeconomic constraints is the task.

2.4.4. Cooperation with farmers and institutions for technology validation and transfer.

From its very beginning and in accordance with the structure of the project outline and the outputs defined, development of soil conservation technology covered nearly all aspects of the research and development cycle outlined in Figure 2.15.

Besides basic research, mainly on soil erodibility, erosivity and the interactions between soil erosion and productivity decline of soils, applied research, dealing with development of technical components and the testing of these within the overall farm situation, occupied most of the time of the project team.

However, linkages to local NGO's and of institutions in the area of natural resources management and rural development in general were sought and developed to improve the impact of the project, identify constraints for technology adoption at institutional and

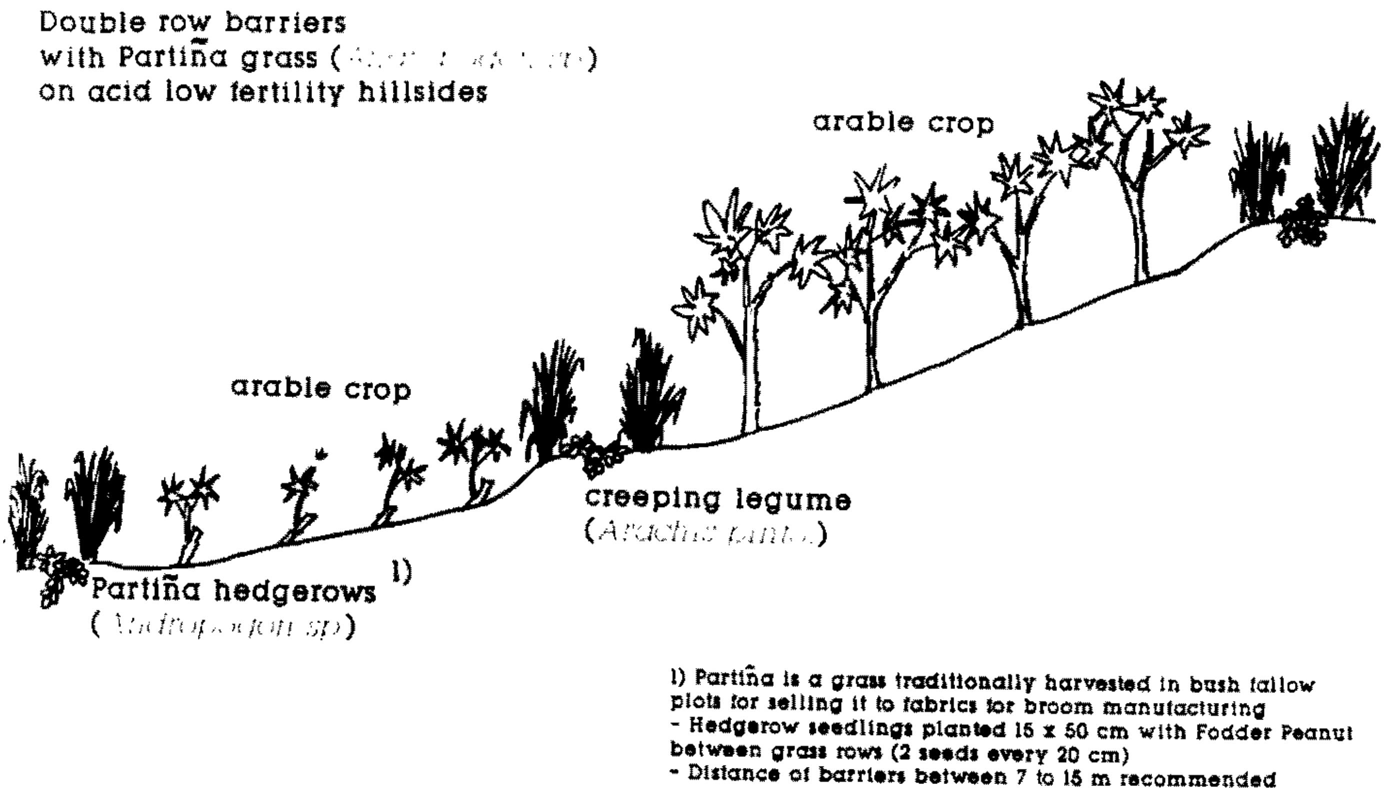
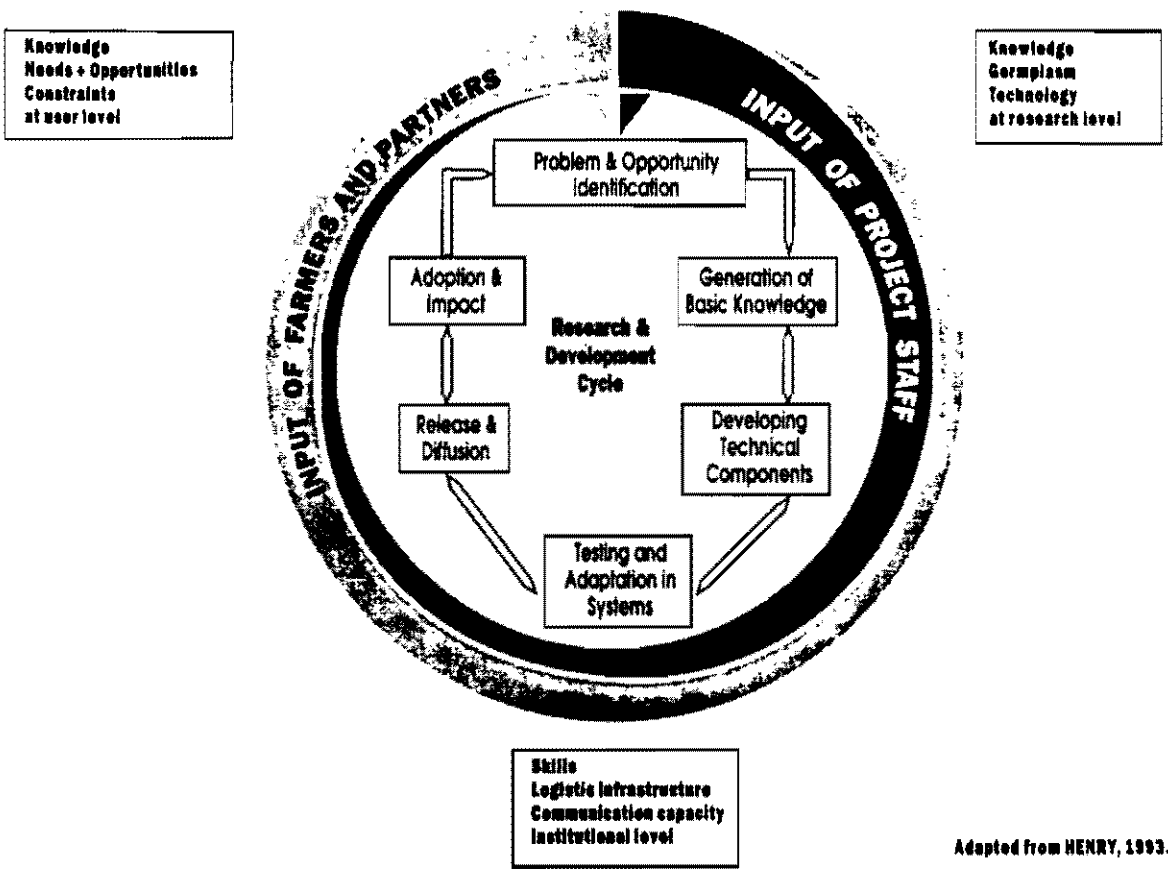


Figure 2.14. Technical illustration showing locally developed recommendation for the use of Partiña as a soil conservation component.

CONCEPTUAL FRAMEWORK FOR DEVELOPMENT OF SOIL CONSERVATION TECHNOLOGY



Adapted from HENRY, 1993.

Fig. 2.15. Conceptual framework for development of soil conservation technology.

farmer (user) level and to obtain the feed back needed to reorient work on technology development.

Though not formally structured and to large degree based on opportunities for collaboration at different levels, working along these guidelines is considered as a valid and successful approach. It requires personnel commitment due to its informal character but gives high flexibility to all partners and was adequate to the size and structure of the existing research oriented project.

Involvement of farmers and farmer's knowledge and concepts occurred at different levels. In the case of the development of Partiña grass as a conservation component (see paragraph 2.4.3.) farmers were involved in all steps of technology development. The need for collaboration from a development oriented NGO, however became evident, when it came to the point of dissemination, market and product development. In this area the two partners, farmers and researchers, could not provide the skills and capacity to overcome the constraints for adaption. Assistance from CETEC was sought for to help in creating a more favourable environment for the technology (small local processing unit for the grass) and for the dissemination of the technology amongst farmers - providing logistical support and credits for improved cassava production.

In another case of collaboration with the National Coffee Federation (FEDECAFE), components (e.g. dwarf elefant grass barriers) were first discussed and evaluated with the technical staff from this institution. Then it was tested with the institution on some farms and afterwards offered to farmers as a technology option to improve productivity and sustainability on their farms. Project staff participated in field days and community workshops providing background information on the need and opportunities for soil conservation and small amounts of conservation germplasm for local multiplication if these were requested or available.

Feedback from farmers came in the form of demand or disinterestedness, from field days, discussions during follow up visits to individual farmers and through extension personnel from the collaborating institution.

Finally, collaboration for technology diffusion was organized in the form of a sub-project with financial collaboration only. An adoption constraint had to be solved through mechanisms and technologies, where the project could not provide the required knowledge and skills. In this specific case, Citronella grass had been identified as a most adequate barrier grass species for farmers without cattle or on fields too distant from the farm for cut and carry use.

Ease of transplanting, high multiplication factors, very good adaptation to a wide range of environments, to acid low fertility soils, resistance to pests and diseases, high biomass production and last not least high contents of an essential oil with acceptable market perspectives made this grass species an interesting option for a soil conservation initiative.

However, there was no technology and institution available to produce and sell the essential oil and/or products derived from it. Under these conditions no farmer would plant the barriers, nor could they be recommended to farmers for large scale application on their fields.

An NGO (FIDAR) with experience in development of small scale rural processing industries, training and organization of farmers groups and applied agronomic work with peasant farmers, was identified. A complementary project for the promotion of citronella and the construction of an oil extraction plant with a rural community was formulated and approved.

By July 1995 the plant is working after several adjustments to reduce energy cost. The rural community is organized, legally registered, trained in bookkeeping and strategies for solving group conflicts and participated in agronomic trials on Citronella management. About 22 ha are planted with Citronella barriers and the pilot plant is producing 5 liter of essential oil a day, pays two laborers and pays for the work involved in the management of the barriers with a small margin of benefit (see below).

In this case project staff was only involved marginally, eg., helped in getting support for these activities from CVC', the official organization for soil and water management in the area and also collaborating with the project in demonstration trials and multiplication activities.

The examples described give an overview on the range of collaborative activities and its character in the project area. By July 1995 the project is directly linked to four farmer communities, maintains collaborative activities with three NGO's, ONE GO and the Coffee Federation.

Collaboration with (poor) farmer communities, NGO's and the governmental institution benefited a lot from the small but very efficiently used collaborative funds. Though only one hundred $US per month and farmer community it facilitated work. Funds were used for buying some inputs, sometimes labour; allowed to help in some emergency cases (earthquake, lack of drinking water), to support local initiatives (plantain planting, house for community meetings) to mention only some examples and of course to overcome the chronical lack of operational money of the official, collaborating partner.

2.4.5. Socioeconomic aspects of conservation technology development.

In the area of economic evaluations and social aspects of soil conservation technology development, an intensive survey on the perception of progressive environmental degradation was done in the municipality of Suarez/Cauca.

Deforestation, burning of grass - and bush fallow and progressive impoverishment of biological diversity in general characterized the situation in this municipality in the last 50 to 80 years.

More than 50 households were visited by two students from the Universidad del Valle to find out how local population perceived this process, if they are aware of the changes that occurred, what indicators they use and if the historical memory of the community is in accordance with reality as far as the history could be reconstructed on the basis of old aerial photos, maps, reports on land use, production, etc.

Preliminary results of this work revealed that drier climatic conditions, fewer and less valuable trees, less crop species that can be grown, and the disappearance of fauna are the indicators most frequently mentioned to characterize this degradation.

In the municipalities of Buenos Aires/Cauca and Caldono (the last site had later to be canceled because of intensive guerrilla activity) diagnostic interviews on the socioeconomic situation of farmers and on practices, knowledge, and attitudes related with soil conservation and fertility management have been done in 1994.

The information from over 120 cassava producing farm units was collected with support from the CIAT, Cassava Economy section, to make sure, sampling and statistics were done according to present standards.

CVC, FIDAR and a local NGO (Grupo de Integración Rural) participated with personnel, vehicles and basic information in the survey. At present they are receiving the results to orient their work with regard to assessing needs, opportunities and to facilitate planning, execution and monitoring of progress in their own work.

The project is using the information in the same way and hopes to repeat the study by the end of the project to evaluate impact of activities induced in the Buenos Aires pilot area.

Partial results from the "Cascajero" hamlet are presented in Appendix 1 with a summary in English.

With regard to the economic evaluation on characterization of barrier components, intensive collection of biophysical data on productivity and labour requirements is presently undertaken. In teamwork with the Hillsides Program these data will be evaluated according to economic and environmental criteria and objectives using a farm simulation computer model that has been designed especially for this region.

Results from economic evaluation of the cultivation and processing of Citronella grass used as hedgerow to prevent erosion are presented in the following table (2.21). Data, though still of preliminary nature show the feasibility of this approach but evaluation could also demonstrate that benefits are moderate considering present prizes and costs.

Table 2.21. Economic evaluation of the production of 1 liter of Citronella oil in the pilot plant in Caldono, Vereda "El Pital" in the Cauca Department of Colombia. Prices in Colombian Pesos ($Col., 1995).

Variable costs	Price/Unit in $Col.
Cost of Citronella leafs entering the plant	3.000
Gas, electricity and water	3.281
Packing	700
Labour cost	2.500
Cost of marketing	125
Total variable cost	9.609
Depreciation equipment	1.302
Administration costs	327
Total fixed cost	1.629
Total cost of production	11.235
Price per liter at market	14.000
Net gain	2.765
Cost/benefit ratio	1:1,24 = 24%

Notes:

- With a new (existing) equipment for generating steam cost of energy (29%) could easily be reduced to the half.
- Besides a rentability of 24% the plant generates employment (40 mandays a month) - and on long term the benefit derived from stopping soil degradation.

2.5 Training and information dissemination

2.5.1. Training of PhD and Master level students between 1993-1995.

- Mr. Wolfgang Felske has finished his field work and is actually evaluating his data and writing up his PhD thesis. Characterization of rotation elements with respect to productivity and erosion could be completed but because of irregular low rainfall, data on rainfall-energy relationships and splash measurements and techniques will be of preliminary character and will require further research.

- Mrs. Felicitas Flörchinger (see also paragraph 2.3.) has been very successful in evaluating the impact of natural erosion and of artificial soil removal on the productivity of Inceptisols and in expressing these changes in units of degradation (soil chemical and soil physical parameters). Three crops (Cowpea, Sorghum and Cassava) are already harvested and in the process of evaluation. So far data are very consistent and good results are expected. Mrs. Flörchinger also joined the CIAT modeling group and will be well acquainted with aspects of modeling when she finishes her PhD work in CIAT.

- Mr. Jesús Castillo, a Colombian Master student, working at the same time as Research Associate of the project team successfully finished his Master carrier. The thesis on the determination of the erodibility factor "K" with new parameters and model equations got a meritorious classification.

2.5.2. Training of graduate students.

Graduate thesis research, already started in the previous project by Karen Tscherning and Lambert Muhr from Hohenheim University could be finished in the ongoing project phase. Besides the documentation of results, three technical papers have been elaborated and have been published or been accepted for publication.

Mr. Tarik Kubach, who had been visiting the project in 1994, finished his Diploma-thesis, an intensive literature review on factors determining erosivity of rainfall and on methods and techniques for its determination.

Two Colombian graduate students, Mr. P. Buritica A. and Manuel Francisco Polanco P., finished a graduate thesis on "The effects of kinetic energy from raindrop impact on aggregates of four soils from sites in southern Colombia". Their thesis was also classified as meritorious by the University Council of the National University of Colombia in Palmira.

Mrs. Luz Marina Giraldo, also from the Faculty of Agriculture of the National University of Colombia is finishing agronomic research on effects of seedling storage, amendment and plant spacing on the establishment, development, efficiency and productivity of three types of grass barriers by September of this year.

Based on promising results from exploratory trials, done with the CIAT Bean-Entomologist on the potential use of oil from Citronella (barrier grass) as a biological control agent, a thesis work on the effectiveness of this oil against damage from White Flies, Empoasca and other bean pests was initiated in 1995 with German C. Villalobos from Palmira.

Postgraduate training experiences from on-going and previous projects contributed significantly to the development of a three-weeks intensive postgraduate course on "Soil Degradation and Conservation in the Tropics". It was offered for the first time by Hohenheim University in August/September 1994, with 13 participants from Latin America, Africa and Asia. This course is supposed to become a permanent component of the Hohenheim Tropical Center's annual postgraduate training program.

Agronomists from national cassava programs in Brazil and Ecuador have made a request for in-service training in CIAT in the second half of 1995 and will visit the project in October, 1995.

2.5.3. Visitors and farmers training.

During the on-going project several field days, always in close collaboration with one or more of our partners (CETEC, CVC, FIDAR and FEDECAFE) were held on demonstration plots in the northern Cauca Department. Approximately four hundred farmers have participated in these activities and have been discussing about the new technology components proposed.

Work with farmer communities also included basic training in crop management, mostly cassava and on-farm trials with new promising varieties from CIAT.

In the municipality of Buenos Aires farmers were trained in the construction of cheap stables for laying hens and in keeping of laying hens within the framework of creating an incentive (feed) for including Pearl Millet or Sorghum in their cropping systems either as temporary barrier strips or in rotations.

A statistic on visitors received by the project at headquarters and on the experimental station in Quilichao is shown in Figure 2.16.

Visitors included individual scientists, staff from local institutions, CIAT visitors in general and students from agricultural faculties in the Departments of Valle, Cauca, Nariño and Antioquia.

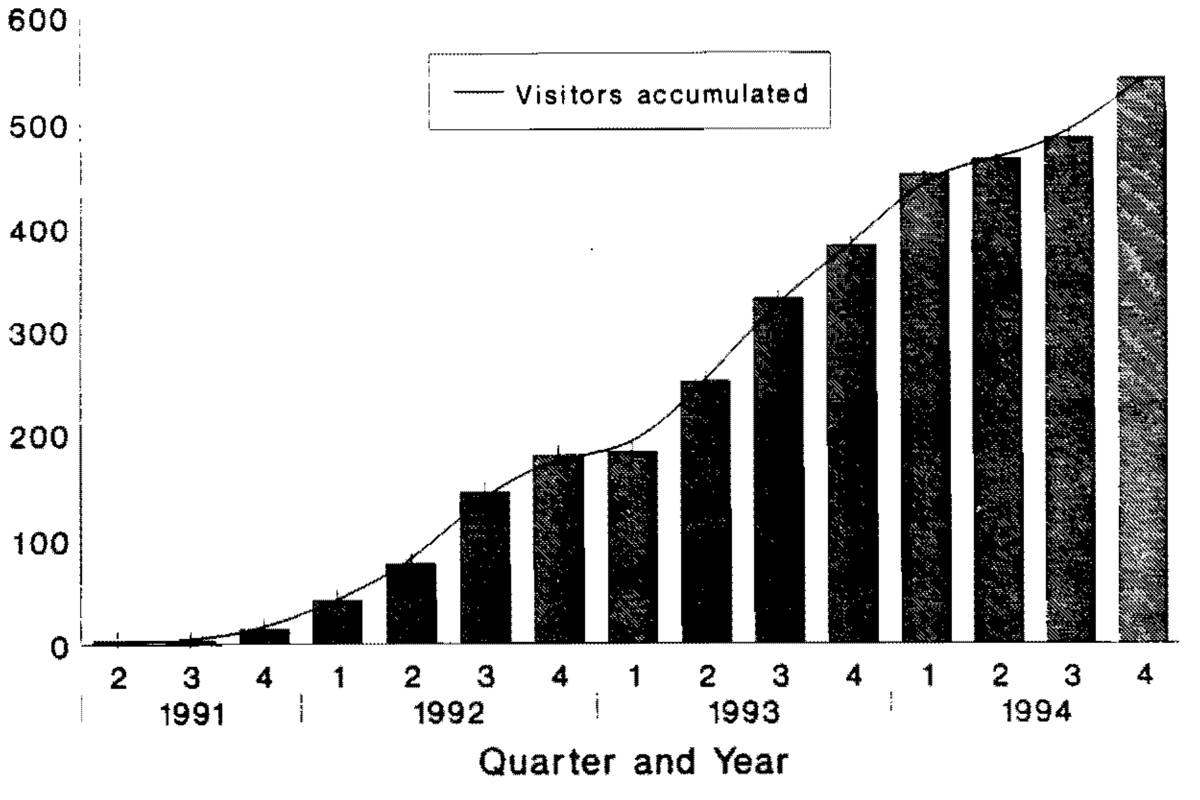


Figure 2.16. Visitors received at headquarter and on Quilichao Experimental Station by the Cassava-Soil Conservation Project until December, 1994.

2.5.4. Dissemination of Conservation Germplasm.

Training and information on new technologies and options for more sustainable land use is not very efficient if materials and germplasm dealt with in the demonstration trials afterwards are not readily made available to farmers.

Therefore the project at an early stage of component development also was pushing the multiplication of these materials and stimulated NGO's and other National Institutions, active in the area of rural development and sustainable land use, to participate in these efforts. Table 2.22 summarizes the balance of these activities where the project team was directly involved.

Table 2.22. Multiplication and distribution of hedgerow germplasm for soil conservation purposes until the end of 1994 [1]. Special project on Soil Conservation/Cassava Program.

Common name	Scientific name	Quantity	Unit
Vetiver	Vetiveria zizanioides	50.415	plantlets
Citronella	Cymbopogon nardus	151.450	plantlets
Lemon grass	Cymbopogon citratus	14.500	plantlets
Dwarf Elefant grass	Pennisetum purpureum cv. Mott	6.650	cane stakes
Imperial grass	Axonopus scoparius	22.075	cane stakes
Guatemala grass	Tripsacum andersonii	500	cane stakes

1) Also a considerable amount of CIAT forage/soil cover germplasm was channeled through project activities to potential clients. Own multiplication of seed was done for Chamaecrista rotundifolia, CIAT No. 8990 and Pearl Millet cv. NCD2 (Pennisetum glaucum).

2.5.5. Publication of research results

The project has started to build a documentation base on research results and technologies tested. The documentation base includes the annual reports of the CIAT cassava program until 1994, five technical papers, two German Ph.D. thesis, one Colombian Master thesis as well as two Colombian and two German graduate thesis. Results of two Ph.D. thesis also have been published as books. Titles of thesis work and technical papers finished so far are listed below. The Ph.D. thesis of Mr. W. Felske, summarizing results from erosion research during 1993-1994 and on preliminary characterization of rainfall-energy relationships is in the process of elaboration.

List of documentation of results:

Buritica, A.P. and Polanco P.M.F.1994. Efecto de dos energias cineticas de la lluvia en cuatro suelos de ladera (Dpto. del Cauca) por el método del impacto gota de lluvia. Tesis de grado, Universidad Nacional de Colombia, Palmira. unpublished.

Castillo, F. J.A. 1994. Determinación del Indice de Erodabilidad (K) en dos suelos del Departamento del Cauca, Colombia. Master Thesis, Universidad Nacional de Colombia, Palmira. pp.206.

Castillo F., J.A., A. Gonzalez M. and K.M. Müller-Sämann, 1995. Determinación del índice de erodabilidad (K) en dos suelos del Departamento del Cauca, Colombia. Suelos Ecuatoriales (paper accepted).

Centro Internacional de Agricultura Tropical (CIAT). 1994. Annual Report for 1993. Cassava Program, CIAT, Cali, Colombia. pp. 173-198.

Centro Internacional de Agricultura Tropical (CIAT). 1995. Annual Report for 1994. Cassava Program, CIAT, Cali, Colombia. p.23 (in press).

Flörchinger, F. and K.M. Müller-Sämann, 1995. Efecto de la remoción del horizonte superficial (erosión simulada) en la productividad del suelo. Suelos Ecuatoriales (paper accepted)

Kubach, T.-A. 1995. Erosivity of rainfall: affecting factors and methods for measurement. Diploma thesis. Hohenheim University, unpublished.

Muhr, L. 1993. Untersuchungen zu unterirdischen Konkurrenzfaktoren in einem Mischanbausystem von Maniok mit Futterleguminosen. Diploma thesis. Hohenheim University. p.87.

Muhr, L., D.E. Leihner, T.H. Hilger, and K. M. Müller-Sämann. 1995a. Intercropping of cassava with herbaceous legumes. I. Rooting patterns and their potential importance for below ground competition. Angew. Bot. 69:17-21.

Muhr, L., D.E. Leihner, T.H. Hilger and K. M. Müller-Sämann. 1995b. Intercropping of cassava with herbaceous legumes. II. Yields as effected by below ground competition. Angew. Bot. 69:22-26.

Müller-Sämann, K.M., M. Ruppenthal and J.A. Castillo F. 1994. Conservación de suelos en yuca. In: Memorias de la Primera Reunión de Agricultura Sostenible en San Gil (Santander, Colombia). CIAT/ CORPOICA, Cali, Documento de Trabajo No. 135:195-226.

Müller-Sämann, K.M.; Castillo, J.A. and Ruppenthal, M. 1994a. Prácticas de conservación de suelos en sistemas de producción de yuca en laderas. En: Memorias del Seminario Manejo Integral de Suelos para una Agricultura Sostenida. Soc. Col. de la Ciencia del Suelo, Palmira. pp. 97-118.

Ruppenthal, M. 1994. Soil erosion and crop productivity in conventional and forage-legume based cassava cropping systems in the South Colombian Andes. Diploma Thesis, Hohenheim University. p.96.

Ruppenthal, M. 1995. Soil Conservation in Andean Cropping Systems. Weikersheim, Margraf. Hohenheim Tropical Agricultural series, 3. p.110.

Tscherning, K. 1992, Untersuchungen zur Konkurrenzwirkung von Grasbarrieren im Maniokanbau auf andinen Hanglagen Kolumbiens. Diploma Thesis, Hohenheim University. p.100

Tscherning, K., D.E. Leihner, T.H. Hilger, K. M. Müller-Sämann and M. El Sharkawy. 1995. Grass barriers in cassava hillside cultivation - Rooting patterns and root growth dynamics. Field Crops Research (accepted for publication).

2.5.6. Soil conservation manual and regional workshop.

Though these outputs were originally scheduled for the regular, three years phase of the project it became more and more obvious that this would affect the quality of both activities and the quality and operations of ongoing research.

As the research activities are still going on during the whole year of 1995, many results would not be available towards the end of the ongoing project, but could be obtained and incorporated during a possible 2 years extension, what would improve the quality and content of the manual.

Furthermore, contacts with NARS in Ecuador, Brazil and Venezuela are just in the process of getting established, so that a workshop at a later point in time seems to be more effective and also more useful in the sense of creating and implementing mechanisms or institutional arrangements that might make the impact of the project within CIAT and within Latin America more sustainable.

Finally, due to an unfavourable development of exchange rates between the US-Dollar and the Colombian Peso the financial situation did not allow to realize the two activities for which no specific budget titles had been assigned.

3. CONCLUSIONS

3.1. Implications for transformation of results into development activities.

As outlined in the workbreakdown structure the overall goal of the project is "to increase incomes and agricultural sustainability in less favoured rural areas by improving the level and stability of cassava production".

The underlying assumption, when formulating this objective, was that higher levels of production and sustainability automatically also lead to increased incomes.

Looking at the long term trends of the impact of innovative management practices on soil erosion and on soil physical parameters, it is clear, that differences between treatments became more and more evident in the course of the years. Consequences for yield, however, were not yet detectable or minimal.

Under these circumstances it might be very difficult to convince farmers to adopt new technologies, because no immediate response in terms of yield increases will occur.

On the other hand, from research done on the impact of erosion on soil productivity on these Inceptisols with a relatively shallow topsoil layer, it is clear, that on a mid to long term perspective yield decline without soil conservation will be dramatic and negatively affect farmer incomes, especially if they do not apply lime and fertilizers.

Not considering the role of possible economic incentives, which nevertheless might be necessary and useful in some cases, an integrated approach is suggested to make integration of (urgently needed) soil conservation technology into development politics a reality.

Points considered of importance are:

a) concentrating on best bet options with proven efficiency and highest economic feasibility (e.g. ridges on fields of moderate slope length, low competitive and/or highly productive barrier elements and productive grass/legume rotation elements instead of weed fallow).

b) provide the infrastructure to make its adoption convenient (e.g. supply of planting material, transport facilities, technical advise).

c) Develop institutional and logistic infrastructure, including the farmers, for selecting, testing and introduction of conservation elements into specific farm environments and production systems. This process has to be combined with extension activities, aimed at an improvement of farm productivity in general (new varieties, better crop management, etc.).

d) Enhancing economic attractiveness of conservation components through the creation of a favourable milieu for setting into value its (sub)-products (e.g. introduction of an animal component for better use of forages, rural processing units for raw material from conservation components such as "Partiña"-grass). These activities have to be linked to favourable market perspectives.

e) Continue research to overcome constraints of promising technology components (eg. search for new species with higher economic value to replace unattractive plants - while maintaining the functional properties of the conservation components).

f) Parallel research efforts are also needed to overcome some basic technical constraints related with potentially very attractive components like undersown legumes (see next paragraph), where mechanisms of competition, variability of competition from different species and sowing technology still need further attention.

Development oriented initiatives on productive, sustainable land use also have to be designed from a farmers point of view and scientists should be given the guidelines and resources to formulate research results in a way, that they fit the needs and opportunities from the demand side.

Interinstitutional arrangements as outlined in Figure 2.4.9 would facilitate such an approach.

3.2. Further research and follow up activities needed

Research on soil erodibility during the last years and observation of erosion dynamics on newly established erosion plots clearly showed, that erodibility K is highly variable on these soils. Changes in organic matter status partly explain these changes, but this indicator, considered in the USLE procedures is not sensitive enough to detect short term changes in soils resistance to erosion as influenced by management and soil use (Oades, 1984).

Especially for this type of soils it is not well understood how and how long management influences bio-physical processes such as soil aggregation through biological agents (Haynes and Swift, 1990), leading to less erodibility of soils. The identification of such "health indicators" for soils susceptibility to erosion requires further research. Practical and low cost indicators have to be identified to guide and orient land use practices and to monitor its impact on soil erosion hazard.

Additional research is also needed on rainfall erosivity and the intensity - energy relationships of rainfall in a tropical Andean environment. Events, so far evaluated do not yet allow general conclusions.

A better understanding of interactions between the water factor and conservation technologies is also necessary and of high practical relevance in subhumid hillsides.

Additional investigation is also recommended on the economics and the social aspects of conservation technologies and on the role of income and market opportunities in the adoption process.

Moreover, by the end of the present project phase, an enormous amount of data from individual thesis research, accumulated over the years will be available. In order to make this information accessible and to facilitate evaluation and use of research results (e.g. in GIS applications) for analyzing long term trends or validating models, the information needs to be compiled in an uniform format.

Alternative model options for calculating erodibility of Inceptisols need further testing on similar sites.

Consolidation and deepening of the established relationships with NARS from Colombia, Brazil and Ecuador should also be sought in a possible extension phase of the project to improve its long term impact on sustainable cassava production in Latin America.

The soil conservation manual and the envisaged regional workshop on soil conservation fit within this strategy and are essential to finish the project.

Networking the scattered activities in different countries of Latin America could further speed up the process of technology development and dissemination.

Integration of legumes into cassava farming systems in the form of an undersown crop, according to the results so far obtained seems impossible with some species or of limited application with more promising, less competitive species like *Chamaecrista rotundifolia*. In the last case this is not primarily due to competition, but because of the lack of adequate equipment for small scale farmers, allowing them to sow small seeded legumes in non tilled or roughly tilled soils.

Development of an adequate, practical low cost sowing implement is considered as an essential step to successful introduction of legumes into peasant farming in hillsides.

Some further research is also recommended to better characterize the principles behind low competition from legumes to widen the germplasm base for different environments and altitudes.

The potential benefits of cover and/or forage legume integration for soil conservation and fertility management in this sector of agriculture would more than justify such an effort.

3.3. Contributions to core-objectives and input into the medium term plan of the centre.

In doing basic and applied research on different aspects of soil erosion, crop productivity, germplasm testing on acid soils and through the development of joint activities with NARS, NGOs and Universities, the project is closely linked to CIAT's new programs of Natural Resources Management - especially "Hillsides".

It thus contributes to CIAT's mission and the objectives formulated for the programs of natural resources management in CIAT's Strategic Plan (1991), and more specifically to the last three goals mentioned below:

1) Characterize farm types and their influence on land use.

2) Development of strategic research on mechanistic models of nutrient cycling, water use and vegetation dynamics, with a view to broad extrapolation of results through techniques such as systems modelling and GIS.

3) Develop and test technology related to:

   - production and soil and water conservation components
   - sustainable land use systems
   - estimating externalities
   - resource management skills required

4) Enhance national research systems through training, pilot projects, networks and documentation.

Though not strictly commodity specific in its structure the project has been housed in CIAT's Cassava Program and put major emphasis on the problems related with peasant cassava production in hillsides. In this sense it also assumed responsibilities for CIAT core activities in the area of soil/crop management, where two senior staff positions had been cut because of reductions in core budget.

At this moment the CIAT Cassava Program is organized along five major project areas:

- Institutional support
- Management of genetic resources
- Gene pool development
- Integrated crop and soil management
- Process, product and market development

The soil conservation project is an integral part of the Mega Project on "Integrated Soil Crop Management" (project CI02), contributing to obtain the following specific outputs formulated in this project for the time between 1994 and 1998.

- Generate knowledge on new technology components and quantification of soil degradation in cassava based systems.

- Develop and evaluate soil fertility maintenance and erosion control practices for specific ecosystems.

- Develop interinstitutional farmer participatory techniques for validating, adopting and selecting component technologies.

- Train national program scientists and extension personnel and the development of intercountry networks.

Research activities of the ongoing project are complemented by a multi-national special project on soil erosion and crop management with a FPR component in South East Asia funded by Sasakawa Foundation, Japan.

Both projects form part of the systemwide initiatives on Acid Soil Management with CIAT and EMBRAPA as CoConveners and on Soil and Water Conservation with IBSRAM as the suggested main convener, where strategic intercentre research was suggested after the CG-meetings in Zschortau and Rome in 1994.

4. OVERALL ASSESSMENT OF PROJECT IMPLEMENTATION AND PERFORMANCE

4.1. Linkages within the center and with the collaborating institute.

The project could be very well integrated into the structure of the CIAT-Cassava Program and actually occupies an important function, equivalent to the former agronomy section within the program.

Addressing mainly aspects of soil fertility management and soil conservation, strong linkages also evolved with the new programs of natural resources management, specifically with the Hillside Program on component development (eg. barriers, cropping systems, data generation for economic assessment of components etc.) and on soil physical aspects with the Tropical Lowlands Program.

Since 1995 the project Coordinator is assisting staff meetings of both programs and thus also forms a link between the commodity oriented Cassava Program and Hillsides.

Working with forage germplasm from the CIAT Genetic Resources Unit and with species recommended and preselected by the Tropical Forages Program also led to much interactions between the project and this program. Through the focus in making use of the germplasm pool is of slightly different nature, interaction was quite extensive and beneficial for both sides.

In an attempt to make Citronella grass a more attractive conservation component collaborative research on the use of Citronella-oil as a biological control agent had recently been initiated between the project and the Bean-Entomology section.

The project Coordinator is also a member of the Scientific Resource Group of CIAT on "Production Systems and Soil Management" and thus linked to issues of common interest that cut across programs and where synergy is sought for to increase efficiency within the center as regards to soil/crop management.

Linkages of the project with the collaborating institute of Plant Production in the Tropics and Subtropics in Hohenheim have always been very intensive throughout the whole course of the project.

Besides the training of Diploma and Ph.D. students, implying a close coordination of research activities and the subsequent publication of results, research outputs also contributed to the elaboration of teaching material for the training of students in Hohenheim.

The project coordinator and Ph.D. students also participated in the post graduate course on "Soil Degradation and Conservation in the Tropics", held annually by the Centre for Agriculture in the Tropics and Subtropics of the University of Hohenheim.

4.2. Major problems and constraints.

Because of the highly complex structure of the project, activities cutting across all aspects of technology development (See section 2.4.5), transaction costs were higher than expected.

Maintaining a two way flow of information between the project and farmers, local institutions and due to the participation in interprogram projects in CIAT (planning meetings, project design, etc.) very few time was left for working on the manual and for organizing the workshop. Besides technical reasons this also contributed to the decision to postpone these activities.

With respect to the financial situation of the project, problems arose from the loss of purchasing power of the US Dollar in the first two years of project execution. Revaluation of the Colombian Peso, relative to the US Dollar and concomitant high inflation rates in Colombia led to a higher annual cost increase than planned and hence to financial bottlenecks in the last year of the project.

In Colombia security standards, in the big cities and on the countryside never have been high. Nevertheless CIAT as an institution or CIAT Staff has never been a target, neither for the guerilla nor for common delinquency.

In the course of the last years the situation has changed for the worse as is shown by the kidnapping of a staff member of CIAT by a guerrilla group (kept prisoner for eight months now) and the increasing rates of criminality in the cities.

Work in two villages in the central cordillera had to be interrupted because of high incidence of guerilla activity and advise of the local population to take more care.

However this has so far not affected the basic structure and the execution of the project but led to minor modifications in the workplan and the loss of some investments in the applied on farm research activities.

4.3. Relation of results and approach.

The approach, chosen for the execution of the project to include and combine activities covering aspects of basic research as well as very applied, adaptive research with groups of peasant farmers was quite successful. It stimulated activities in both areas. Members of the team normally got a good understanding of the needs and opportunities at the farmers and at the institutional level to orient more basic research. The work on farm and with local institutions, on the other hand, could benefit from the research on the basic understanding of erosion processes and potential means to come to practical solutions.

Probability to meet poor farmers and NARs needs (the principle clients of the centers) was favoured by this structure of the project.

The outputs provided consist basically in the generation of viable technology components for improved soil management, supplied with the corresponding background information on the problems and mechanisms which have to be addressed.

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APPENDIX 1

VEREDA "EL CASCAJERO"
MUNICIPALITY OF BUENOS AIRES/CAUCA

First contacts with a farmers group "Empresa Comunitaria los Limones" were established in late 1991. First trials on cassava production, varieties and grass barriers were started in 1992. Support was also given to stimulate land use along the Cauca River with high value crops (tomato, beans, pumpkins, plantain).

A forestry trial was set up in 1992 but species selected failed to produce in this environment.

Converting hillsides into grassland (*Brachiaria humidicola*) was adopted by some farmers but they had to sell the cattle because the group couldn't pay back the credits (two cattle died).

Millet was introduced at one farm in 1994. Parallel introduction of layer hens was subsidized to create an incentive for millet production (chicken feed) at the same time reducing problems of soil erosion (strips).

Actually efforts are undertaken to stimulate development of farm based diets to reduce costs of egg production. This work should mainly be carried out by CETEC, a NGO with experience in this area. The project was successful in linking CETEC to this farm community. The Soil Conservation Project provides information, germplasm and basic agronomic concepts with potential for improved production and soil management and 600 US$ a year for supporting activities of farmers.

Partiña grass, used for broom fabrication and sold to intermediaries is normally collected in bush fallow plots and could successfully be transplanted and multiplied. It is now grown in barriers for combining soil conservation and Partiña production.

A project for combining Partiña production with processing and commercialization is formulated with CETEC. Some characteristics of farm units and attitudes to soil management are given on the next page.

PARTIAL RESULTS OF A DIAGNOSTIC INTERVIEW DONE IN 1994 IN THE MUNICIPALITY OF BUENOS AIRES/CAUCA.

Subset:	Vereda "El Cascajero"
Target group:	"Cassava exploitation units" (fincas) with more than 1 ha and less than 20 ha.
Total size of sample:	69 farms 29 farms interviewed (confidence level 95%, permissible error 15%)
Organizations participating:	CIAT (Soil Conservation Project/Cassava) CVC (Soil Section) FIDAR (NGO) GIR (Grupo de Integración Rural, La Balsa, local NGO)

A. Farmers situation:

No. of persons per household		3.9 persons
Households with water		0,0 %
Distribution of farm sizes:	1-4 ha	65,2 %
	5-9 ha	18,8 %
	10-20 ha	15,9 %
Mean farm size		7,5 %

B. Land use pattern:

Fallow land	3,3 ha
Pasture and grassland	1,9 ha
Cassava	1,4 ha
Others	0,9 ha

C. Crop production:

Four main problems of production in general

a) Soil degradation (fatigue)	16,9 %
b) Pests and diseases	11,3 %
c) Lack of credit	7,4 %
d) Climate	5,6 %

Four main problems of commercialization:

a) Low and unstable prices	23,9 %
b) Retarded payment of clients	11,3 %
c) Transport	5,6 %
d) Selling at market	4,3 %

Mean yields in cassava production

- Fresh root yield, monocrop	6,8 t/ha

D. Soil erosion aspects:

a) Percent of farmers that observed the phenomenon of soil erosion — 96,5 %

b) Answers to the question how soil losses affect plant production:

- reduces yields	96,5 %
- don't know	3,5 %

c) Percent of farmers burning the fallow residues before planting — 79,6 %

d) Practices applied to avoid soil losses ("evitar arrastre de tierra"):

- Reduced tillage (preparing planting holes only)	29,7 %
- None	24,3 %
- Residue barriers	8,11 %
- Drainage ditches	8,11 %
- Rotations	8,11 %
- Liver barriers	5,4 %
- Weeds	2,7 %

e) Main reasons for not applying soil conservation practices:

- Lack of technical assistance	34,8 %
- High costs implied	26,1 %
- Lack of time	17,4 %
- Lack of access to materials	4,4 %

E) What kind of trees would you plant

- Fruit trees	32,2 %
- Live fences	17,3 %
- Timber trees	11,5 %
- Shade trees	10,3 %
- Forage trees	8,1 %
- Fuel trees	8,1 %