Research Network for the Evaluation of Carbon Sequestration Capacity of Pasture, Agropastoral and Silvopastoral Systems in the American Tropical Forest Ecosystem

CIPAV- Universidad de la Amazonia -CIAT-CATIE-
Wageningen University and Research Centre

The Netherlands Cooperation
Activity CO-010402

Project duration: 5 years
December 1, 2001 – November 30, 2006

Six-months Technical Report no. 6

June 1- November 30, 2004

María Cristina Amézquita
Project Scientific Director

Presented to The Netherlands Cooperation, channelled through The Netherlands Embassy in Bogotá, Colombia. December 15, 2004.

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- Preparation and handling to the Netherlands Embassy in Bogotá, of the Fifth Six-months Technical and Financial Reports for the period December 1, 2003 – May 31, 2004.
- Participation with a scientific paper at the I World Agroforestry Congress held at Orlando, Florida, USA, June 27 – July 2, 2004. The paper was invited to be published at the International Journal for Sustainable Forestry, edited by Yale University, USA (Annex 2).
- As a result of the participation at the Workshop for the Potential of Carbon Sequestration in Latin America, sponsored by USAID, USDA, Ohio State University (OSU) and University of Sao Paolo, held at Piracicaba, Brazil, from May 31- June 6, 2004, the project was invited to prepare a scientific paper entitled "Carbon Sequestration Potential of Pasture and Silvo-pastoral Systems in the Tropical Andean Hillsides" to be published as a chapter of a book edited by The Ohio State University, USA (Annex 3).
- Conduction of the Fifth International Coordination Meeting, Punta Leona, Costa Rica, July 26-29, 2004. Meeting program and recommendations are included as Annex 8.

2.2 Research Activities

- Second C-sampling cycle of long-established land use systems, Andean Hillsides Ecosystem, Colombia. March – July 2004. Statistical analysis of corresponding data was carried-out during September-November 2004. Annex 4.1 of this report presents the descriptive and inferential statistical analysis.
- Evaluation of fine root biomass from long-established systems, Andean Hillsides Ecosystem. Annex 4.2 of this report presents summary results.
- Second C-sampling cycle of long-established land use systems, Humid Tropical Forest, Amazonia Ecosystem, Colombia. Field work was carried-out in September-November 2004. Soil samples were taken to CIAT's Soils Laboratory for analysis. Results are expected for early 2005.
- Second C-sampling cycle of long-established land use systems, Humid and Sub-humid Tropical Forest, Costa Rica. Field work was carried-out in August-November 2004. Soil samples were taken to CATIE's Soils Laboratory for analysis. Results are expected for early 2005.
- Analysis of socio-economic data from research areas in all ecosystems.
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Annex 3: Second project scientific publication: "Carbon Sequestration Potential of Pasture and Silvo-pastoral Systems in the Tropical Andean Hillsides". By M.C. Amézquita, P. Buurman, E. Murgueitio and E. Amézquita. Submitted for Publication on Oct 27, 2004, as a chapter of the Scientific book entitled "Carbon Sequestration Potential in Latin America", to be published by The Ohio State University, USA.

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Acknowledgements

We express our gratitude to The Netherlands Ministry of Development Cooperation in The Hague, and The Netherlands Embassy in Bogotá, Colombia for making real this important project.

Our project combines efforts from the national research community --represented by CIPAV and Universidad de la Amazonía, Colombia-- and the international research community --represented by CIAT, CATIE and Wageningen University and Research Centre-- to help prepare ourselves and our future generations to mitigate the effects of global warming. Our hope is to achieve relevant high quality research results that will contribute to mitigate the adverse effects of global warming in vulnerable ecosystems of the developing world, as the American Tropical Forest Ecosystem.

The present document ***"Six-months Technical Report No. 6: June 1- November 30, 2004"*** reports on project advances during the second semester of the third year of project's implementation, in agreement with the project Annual Plan 2004. The most important research activities during this semester were: a) Second C-sampling cycle in all project sub-ecosystems, as planned at the beginning of the project; b) In-depth socio-economic analysis of "improved farms" vs. "conventional farms" in research areas of the three project sub-eco-systems (Andean Hillsides, Colombia, Tropical humid forest, Colombian Amazonia, and Sub-humid and humid tropical forest, Costa Rica); c) Continuation with periodic biomass evaluation of the five small-plot experiment established on degraded land in Amazonia, Colombia (2 experiments), Andean Hillsides, Colombia (2 experiments) and Costa Rica sub-humid tropical forest (1 experiment).

It is our pleasure to inform that project scientists are actively participating at scientific and policy-oriented congresses, workshops and other events on carbon sequestration and related topics, at national and international level. This fact is an important recognition of the high scientific quality of the work being done by project team and the relevance of present project's results. Two scientific papers have been submitted and accepted or publication in internationally recognised scientific journals.

We are pleased to inform that activities conducted and completed during the second semester of our third year are in full agreement with the project Annual Plan 2004. We thank project member and consultants for their fruitful discussions, valuable contributions and efficient work done.

With best wishes for future success in our project's fourth year.

María Cristina Amézquita
Ph. D. in Production Ecology and Resource Conservation
Project Scientific Director
Cali, Colombia, December 15, 2004.

Participant Institutions

- **CIPAV**: Centre for Research on Sustainable Agricultural Production Systems, Cali, Colombia.
  Legal and technical representative: Dr. Enrique Murgueítio, Executive Director.
- **Universidad de la Amazonia,** Florencia, Colombia.
  Legal representative: Dr. Oscar Villanueva Rojas, Rector.
  Technical representative: Dr. Bertha Leonor Ramírez, researcher.
- **CIAT**: International Centre for Tropical Agriculture, Cali, Colombia.
  Legal representative: Dr. Joachim Voss, Director General.
  Technical representative: Dr. Edgar Amézquita, Soil Scientist.
- **CATIE**: Centro Agronómico Tropical para Capacitación y Enseñanza, Turrialba, Costa Rica.
  Legal representative: Dr. Pedro Ferreira Rossi, Director General.
  Technical representative: Dr. Muhammad Ibrahim, researcher.
- **Wageningen University and Research Centre**, Wageningen, The Netherlands.
  Representatives: Drs. Bram van Putten and Peter Buurman, researchers.

Project Executive Committee

- **Dr. María Cristina Amézquita.**
  Ph.D., Production Ecology and Resource Conservation.
  Project Scientific Director.
- **Dr. Enrique Murgueitio**. CIPAV's Executive Director.
  Project Administrative and Financial Director.
- **Bertha Leonor Ramírez**. Ph.D., Agroforestry Systems.
  Universidad de la Amazonía.
- **Dr. Edgar Amézquita**. Ph.D., Soil Sciences. CIAT.
- **Dr. Muhammad Ibrahim**. Ph.D., Agronomy. CATIE.
- **Dr. Bram van Putten**. Ph.D., Mathematics.
  Wageningen University and Research Centre.
- **Dr. Peter Buurman**. Ph.D., Soil Chemistry and Dynamics.
  Wageningen University and Research Centre.

Consultant

- **Professor Dr. Leendert 't Mannetje,** Ph. D. in Tropical Grasslands.
  Wageningen University and Research Centre.

Project members

- ***Field research – Hillsides ecosystem (Colombia)***
  María Elena Gómez. Agronomist, M.Sc.- CIPAV (80% time)
  Piedad Cuellar. Participatory research, M.Sc.- CIPAV (50% time)

- ***Field research – Semi-humid Tropical Forest (Costa Rica)***
  Tangaxuhan Yanderall, PhD student
  Alexander Navas, Agronomist, CATIE
  Francisco Casasola, Agronomist – CATIE (part time).

- ***Field research – Humid Tropical Forest (Colombian Amazonia)***
  Bertha Leonor Ramírez. Agroforestry Systems. Ph.D. (full time).
  Jaime Enrique Velásquez. Agronomist. Ph.D (part time).
  Jader Muñoz, Geologist (part time).
  B.Sc. students (part time): Jaime Andrés Montilla y Juán Carlos Suárez
  Universidad de la Amazonia.

- ***Environmental Economist:***
  José Gobbi, Economist Ph.D. (35% time).

- ***Mathematical modelling***
  M.Sc. students under Dr. Bram van Putten. Wageningen University (part time).

- ***DB analyst/statistician***
  Héctor Fabio Ramírez. Statistician (half time).

- ***Soil sampling and biomass measurement***
  Hernán Giraldo. Agronomist (full time).

- ***Executive Assistant***
  Francisco Ruiz. Industrial Engineer (full time).

Research Services

- ***Laboratory analyses***
  Samples from Colombian ecosystems: contracted with CIAT.
  Samples from Costa Rica ecosystem: contracted with CATIE.

- ***GIS (cartography and 3D images)***
  To be possibly contracted with CIAT or with ISRIC, Wageningen University.

Research Network for the Evaluation of Carbon Sequestration Capacity of Pasture, Agropastoral and Silvopastoral Systems in the American Tropical Forest Ecosystem

CIPAV- Universidad de la Amazonia -CIAT-CATIE-
Wageningen University and Research Centre

1. Background

1.1 PROJECT EXECUTIVE SUMMARY

The present multi-institutional research project was presented by a developing country (Colombia) to The Netherlands Ministry of Development Cooperation, through The Netherlands Embassy in Bogotá, Colombia, for financial support consideration. Its broad research topic is Climate Change: mitigation alternatives for vulnerable ecosystems in developing countries. It combines efforts from the national research community, represented by CIPAV and Universidad de la Amazonía, and the international research community, represented by CIAT, CATIE and Wageningen University and Research Centre, to help prepare ourselves and our future generations to mitigate the effects of global warming. This research project responds to the United Nations Framework Convention on Climate Change (UNFCCC, New York, May 9, 1992; last modified on 11 October 2000) Article 3 (numeral 2), Article 4 (numerals d and g), Article 5 (numerals a and b), Article 12 (numeral 4), Kyoto Protocol Article 10 (numeral d), The Bonn Agreement (COP6 - July, 2001), The Marrakesh Conference (COP7 - Nov, 2001) and The Netherlands Implementation of Clean Development Mechanism (CDM) and related research on mitigation alternatives (October 22, 2001). It consulted the 1996 IPCC Guidelines for National Greenhouse Gas Inventories, and Winrock (2000) methodology for monitoring carbon storage in agroforestry projects.

The project main goal is to contribute to sustainable development, poverty alleviation and mitigation of the undesirable effects of climate change, in particular CO_2 *emissions, in vulnerable sub-ecosystems of the American Tropical Forest ecosystem. This main goal will be attained through conduction of scientific research and systematic observations on a range of pasture, agropastoral and silvopastoral systems, in small, medium-size and large farms, in three sub-ecosystems of the American Tropical Forest ecosystem vulnerable to climate change: the eroded Andean hillsides of Colombia (densely populated), the semi-humid tropical forest of Costa Rica (densely populated), and the humid tropical forest of the Amazonian region in Colombia (zone of social conflict).*

> *Research aims at identifying improved and sustainable pasture, agropastoral and silvopastoral systems that provide a viable and economically attractive solution to the farmer (alleviating poverty) and offer environmental services, particularly increases in soil organic matter, carbon accumulation and act as carbon sinks. Research will be conducted in Colombia and Costa Rica. Emphasis is given to poverty alleviation; in the sense that this research aims at demonstrating that enhancing C accumulation and protecting carbon sinks is an economically attractive activity for farmers.*
>
> *Project duration is 5 year, from December 1, 2001 to November 30, 2006. Total project cost is US$ 3,698.525. Financial support approved by The Netherlands Ministry of Development Cooperation, channelled through The Netherlands Embassy in Bogotá, Colombia, is US$1,381.765 representing 37 % of the project total cost.*

1.2 THE PROJECT: MAIN GOAL, OBJECTIVES, EXPECTED PRODUCTS AND RESEARCH METHODOLOGY.

MAIN GOAL

To contribute to sustainable development, poverty alleviation and mitigation of the undesirable effects of greenhouse gasses on climate change, in particular CO_2, in vulnerable sub-ecosystems of the American Tropical Forest ecosystem.

Sub-ecosystems considered within the American Tropical Forest ecosystem are:
(a) Eroded Andean hillsides of the semi-evergreen seasonal forest (H)
(b) Flat and mild-slope areas of the semi-humid tropical forest of low altitude (SHF)
(c) Flat and mild-slope areas of the humid tropical forest (HF) .

Land managements systems to be monitored and evaluated include: degraded pasture (negative control), native pasture, improved grass-alone pasture, improved grass with herbaceous legume, improved grass with woody legumes, improved grass with other trees (fruit trees, wood trees), forage banks, "barbechos"/"charrales"/"rastrojos" and natural forest (positive control). Table 1 shows the land management systems to be evaluated within each sub-ecosystem.

Table 1: Land Management Systems to be evaluated within each sub-ecosystem		H	SHF	HF
1. Degraded land and degraded pasture →	- CONTROLS	✓	✓	✓
2. Native pasture			✓	✓
3. Improved grass-alone pasture		✓	✓	✓
4. Improved grass-herbaceous legume			✓	✓
5. Improved grass-woody legumes				✓
6. Grass–other trees (fruit trees, wood trees)			✓	✓
7. Forage banks for "cut and carrying"		✓	✓	✓
8. "Charrales", "barbechos", "rastrojos"			✓	✓
9. Natural Forest →	+ CONTROL	✓	✓	✓

OBJECTIVES

(1) **Compare** the various land management systems within each sub-ecosystem, in order to **identify** those that are more economically attractive to the farmer (help alleviate poverty) and have higher levels of carbon accumulation and carbon sinks.
(2) **Perform an economic evaluation** of these land management systems in terms of their benefit associated with carbon accumulation and carbon sinks.
(3) **Provide recommendations** on appropriate technology and management for these land management systems in order to make them economically attractive to the farmer and beneficial to the environment as contributors to increases in carbon sequestration and carbon sinks.
(4) **Develop cost-effective methodologies for C monitoring** in these different land management systems.
(5) **Develop mathematical models to extrapolate carbon sequestration capacity** in similar areas within the American Tropical Forest Ecosystem for future decision-making in research and policy-making.

EXPECTED PRODUCTS

- **Identified** pasture, agropastoral and silvopastoral systems that are viable and economically attractive to the farmer and enhance C accumulation and sinks.
- **Estimated** carbon levels, animal productivity and farmer's economic benefit in the various land management systems studied across sub-ecosystems.
- **Estimated** economic benefit of C accumulation in these land managements systems.
- **Recommended** policy guidelines developed for paying C incentives to farmers in these land management systems in the tropics.
- **Shared new knowledge** with farmers, researchers and policy-makers invited to field days and training events.
- **Better knowledge of C accumulation levels** in these complex pasture, agropastoral and silvopastoral systems in the tropics.
- **Refined criteria, methodology and scientific information** for future research on carbon sequestration in pasture, agropastoral and silvopastoral systems in the tropics.
- **Identified land-use systems and sites for targeting CDM** within the American Tropical Forest Ecosystem.

RESEARCH METHODOLOGY

Research methodology for this 5-year project was discussed in detail and agreed by participant institutions, project members and consultants during the First International Coordination Meeting, held at CIAT, December 17-19, 2001 and improved in subsequent meetings and discussion sessions. Research methodology is common across sub-ecosystems and comprises the four following research strategies:

A. Evaluation of a range of long-established land management systems of similar age within each sub-ecosystem (11-20 years of age) to quantify and compare the level of C accumulation between them and in comparison with two extreme reference states: degraded pasture (negative control) and native forest (positive control).
B. Evaluation of new small-plot experiments established on degraded pasture sites, to quantify and compare after 4 years the level of C accumulation newly established improved systems vs. the degraded pasture.
C. Socio-economic evaluation of research areas, farms and land use systems.
D. Model building to estimate C accumulation in silvopastoral systems.

2. Activities 2nd semester year 3 (June 1– Nov 30, 2004) according to Annual Plan 2004

The activities described below have been successfully accomplished during the second six months of the third year of our project: June 1 – November 30, 2004, in accordance with Annual Plan 2004. The Chronogram of Activities 2004 is included as Annex 1 of the present report.

Technical and administrative coordination activities

1. **Preparation and handling of Fifth Six-months Technical and Financial Reports December 1, 2003 – May 31, 2004.** They were handled to The Netherlands Embassy in Bogotá on June 30, 2004.
2. **Scientific publication 1.**- As a result of the project participation with a scientific paper at I World Agroforestry Congress, Orlando, Florida, USA, June 27 – July 2, 2004. Paper invited for publication at the International Journal for Sustainable Forestry, edited by Yale University, USA. The full paper is included as Annex 2 in this report.
3. **Scientific publication 2.**- As a result of the Scientific Director participation at the Workshop for the Potential of Carbon Sequestration in Latin America, sponsored by USAID, USDA, Ohio State University (OSU) and University of Sao Paolo, held at Piracicaba, Brazil, from May 31- June 6, 2004, the project was invited to prepare a scientific paper entitled "Carbon Sequestration Potential of Pasture and Silvo-pastoral Systems in the Tropical Andean Hillsides", paper to be published as a chapter of a book edited by The Ohio State University, USA. The full paper is included as Annex 3 in this report.
4. **Conduction of the Fifth International Coordination Meeting**, Punta Leona, Costa Rica, July 26-29, 2004. Meeting program and recommendations are included as Annex 8 of this report.

Research Activities

It is our pleasure to inform that research activities conducted and completed during the second semester of our third year are in full agreement with the project Annual Plan 2004. The most important research activities during this semester were:

a) Second C-sampling cycle of long-established land use systems, Andean Hillsides Ecosystem, Colombia. Field work was carried-out during March – July 2004. Statistical analysis of corresponding data was carried-out during September-November 2004. Annex 4.1 of this report presents the descriptive and inferential statistical analysis.
b) Evaluation of fine root biomass from long-established systems, Andean Hillsides Ecosystem. Annex 4.2 of this report presents summary results.
c) Second C-sampling cycle of long-established land use systems, Humid Tropical Forest, Amazonia Ecosystem, Colombia. Field work was carried-out in September-November 2004. Soil samples were taken to CIAT`s Soils Laboratory for analysis. Results are expected for early 2005.
d) Second C-sampling cycle of long-established land use systems, Humid and Sub-humid Tropical Forest, Costa Rica. Field work was carried-out in August-November 2004. Soil samples were taken to CATIE`s Soils Laboratory for analysis. Results are expected for early 2005.
e) In-depth socio-economic analysis of "improved farms" vs. "conventional farms", conducted by José Goobi in collaboration with researchers from Andean Hillsides, Amazonia and Costa Rica sub-ecosystems. The report form José Gobbi is presented as Annex 4 of this report. It includes methodology and socio-economic indicators attained at the three sub-ecosystems.
f) Continuation with periodic biomass evaluations of small-plot experiments in all project sub-ecosystems under research (see Annexes 5,6 and7).
g) Consolidated analyses of soil carbon data from the Sub-humid and Humid Tropical Forest Sub-ecosystem, Costa Rica. An advance report is here included as Annex 5, prepared by Mhammad Ibrahim and Tangaxhuan Llanderal from CATIE (Annex 5).

3. Budget

Budget tables 1-9 in Annex 9 of this report show real budget execution for years 1-3 and estimated budget requirements for years 4-5. The tables show project budget, global and per institution/year, discriminated by donor funds and matching funds.

Annex 1

Chronogram of Activities
Annual Plan 2004

CHRONOGRAM OF ACTIVITIES - ANNUAL PLAN 2004

December 1, 2003 - December 31, 2004

OBJECTIVE	ACTIVITY	INDICATORS	12	1	2	3	4	5	6	7	8	9	10	11	12	Participant Institutions
1. PROJECT ORGANISATION ACTIVITIES.	Preparation and agreement of annual contracts for project personnel	Signed contract														CIPAV
	Preparation and agreement of Terms of Reference for Consultants	Accepted TOR´s	■	■												Project Direction CIAT WU
	Renewal of contract with farmers for the three sub-ecosystems: Andean Hillsides, Amazonia and Costa Rica farms.	Contracts accepted. Farms ready to work.			■											U.AMAZONIA, CIPAV and CATIE
2. TECHNICAL AND ADMINISTRATIVE COORDINATION	Preparation of ANNUAL PLAN 2004	Plan handled to The Netherland Embassy in Bogotá, Colombia (February 29, 2004)			■											Project Direction
	Fifth International Coordination Meeting Punta Leona, Costa Rica, July 26-29, 2004	Meeting conducted								■						Project Direction CATIE CIAT CIPAV U.AMAZONIA W.U
	Preparation of Fifth Six-months Technical and Financial Reports.	Reports handled to The Netherlands Embassy in Bogotá, Colombia. June 30, 2004.						■	■							All Participant Institutions
	Preparation of Sixth Six-months Technical and Financial Reports.	Reports handled to The Netherlands Embassy in Bogotá, Colombia, before Dec 31, 2004.											■	■	■	Project Direction CIAT CIPAV CATIE U.AMAZ. W.U
	Preparation of ANNUAL PLAN 2005.	Plan handled to The Netherlands Embassy in Bogotá, Colombia (December 31, 2004).													■	Project Direction and Participant Inst.

CHRONOGRAM OF ACTIVITIES - ANNUAL PLAN 2004
December 1, 2003 - December 31, 2004
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OBJECTIVE	ACTIVITY	INDICATORS	12	1	2	3	4	5	6	7	8	9	10	11	12	Participant Institutions
3. SOCIO-ECONOMIC SIMULATION TOOL	Data selection and use of simulation software. Three Sub-ecosystems	Tool ready. Simulation scenarios analyzed					■	□	▨	■						Project Direction and CATIE Economics consultant
4. SECOND CARBON SAMPLING. AMAZONIA - COLOMBIA, HILLSIDES - COLOMBIA AND COSTA RICA SUB-ECOSYSTEMS	1. Soil carbon and vegetation evaluations - six new treatments. Amazonia - Colombia	Data organised according to agreed formats						▨	▨				■			Project Direction U. Amazonia
	2. Soil carbon and vegetation evaluations - second spacial replication, Hillsides - Colombia	Data organised according to agreed formats									□	□		■		Project Direction CIPAV
	3. Soil carbon and vegetation evaluations - second spacial replication, Costa Rica	Data organised according to agreed formats					■	■	■							CATIE
5. EVALUATION OF SMALL-PLOT EXPERIMENTS - BIOMASS PRODUCTION	Andean Hillsides-Colombia.	Two experiments evaluated every 2 months.		□		□		□		□		□		□		CIPAV
	Humid Tropical Forest - Colombian Amazonia	Two experiments evaluated every two months		▨		▨		▨		▨		▨		▨		U. Amazonia
	Semi humid and humid Tropical Forest - C. Rica	One experiment evaluated every two months.		■		■		■		■		■		■		CATIE

CONVENTIONS:

■ EXECUTED BY PROJECT DIRECTORS
▨ HUMID TROPICAL FOREST, COLOMBIA - U. AMAZONIA
□ ANDEAN HILLSIDES, COLOMBIA - CIPAV
■ SEMI-HUMID TROPICAL FOREST, COSTA RICA -CATIE
■ WAGENINGEN UNIVERSITY PARTICIPATION
CIAT PARTICIPATION

Annex 2

Project Scientific Publication no. 1
"Carbon Sequestration in Pasture and Silvo-pastoral Systems in four different ecosystems of the Latin American Tropics"

By M.C. Amézquita, M. Ibrahim, T. Llanderal,
P. Buurman and E. Amézquita

Submitted for Publication at the International Journal of Sustainable Forestry – Special Issue, on Nov 8, 2004.

Carbon Sequestration in Pasture and Silvo-pastoral Systems in four different ecosystems of the Latin American Tropics

María Cristina Amézquita[1], Muhammad Ibrahim[2], Tangaxuhan Llanderal[3], Peter Buurman[4] and Edgar Amézquita[5]

ABSTRACT. Tropical America (TA) holds 8% of the world's population, 11% of the world's continental area, 23% and 22%, respectively, of the world's forest and water resources, and 13% of the world's pasture and agro-pastoral land, this representing 77% of TA's agricultural land. Milk and meat production in TA's countries have important socio-economic significance. Improved and well-managed pasture systems have increased the production and quality of milk and meat as well as farmers' economic welfare, export market competitiveness and economic development. Recent interest in carbon sequestration and preliminary research suggest that well-managed pasture systems in TA could provide a good combination of economic production, poverty reduction, recovery of degraded areas and delivery of environmental services, particularly, carbon sequestration. This paper presents 3-year research results generated by the "Carbon Sequestration Project, The Netherlands Cooperation CO-01002" on soil carbon stocks (SCS) for a range of pasture and silvo-pastoral systems prevalent in agro-ecosystems of TA compared to native forest and degraded land. SCS were estimated based on fixed soil depth (Mg/ha/1m) and fixed soil mass (Mg/ha/1m-equiv). We have found that in the tropical Andean hillsides, Colombia, SCS from *Brachiaria decumbens* pastures were statistically lower than those from native forest, but higher than those from natural regeneration of a degraded pasture (fallow land), degraded pasture and mixed-forage bank. In contrast, in the humid tropical forest of the Atlantic Coast, Costa Rica, pasture or silvo-pastoral systems with native or planted pasture species such as *Ischaemum ciliare, Brachiaria brizantha* + *Arachis pintoi* and *Acacia mangium* + *Arachis pintoi* showed statistically higher SCS than native forest. Similar rankings were found in the humid tropical forest of Amazonia, Colombia, where improved *Brachiaria* pastures (monoculture and legume-associated) showed statistically higher SCS than native forest. In conclusion, in tropical ecosystems, improved pasture and silvo-pastoral systems show comparable or even higher SCS than those from native forests, depending on climatic and environmental conditions (altitude, temperature, precipitation, topography and soil), and represent attractive alternatives as C-improved systems.

KEYWORDS. Tropics, soil carbon stocks, tropical pastures, silvo-pastoral systems.

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5. Edgar Amézquita is a Soil Scientist from CIAT, Cali, Colombia. Member of the above project. Email: e.amezquita@cgiar.org

Introduction

Tropical America (TA) comprises Mexico, Central America, the Caribbean and South America, excluding Argentina, Chile and Uruguay. It covers 1,688 million ha representing 11% of the world continental area, and houses 432 million people representing 8% of the total world population; forests cover 41% of its territory --a very high proportion compared with the world proportion in forests (28%)-- and represent 22% of the world forest area; water renewable resources in the region are abundant, representing 22% of the world freshwater resources, with an average per-capita availability of 35,405 m^3 in TA, almost five times the corresponding world average, of 7,176 m^3 (FAO, 2000). TA's agricultural land amounts to 548 million ha corresponding to 32% of its territory and to 11% of the world agricultural land; of its 432 million inhabitants, 100 million (23%) are farmers, representing 4% of the world population who live from agricultural and livestock production activities; TA's agricultural land includes crop and pasture (both native and introduced), silvo-pastoral and agro-silvo-pastoral land (FAO, 2000).

Pasture, silvo-pastoral and agro-silvo-pastoral land represent 77% of TA's total agricultural land, mostly on poor acid soils, while crops cover the remaining 23%, mostly located on better quality soils, with a pastures/crop land ratio of 3.4, higher than the world ratio of 2.3. TA holds 21% of the world's cattle inventory and 18% of the world's inventory of dairy cows. Pasture systems, as well as meat and milk production, are concentrated in four countries: Brazil, Mexico, Colombia and Venezuela. Together they hold 76% of the pasture and agro-silvo-pastoral land, 84% of total cattle inventory, 85% and 83% respectively of meat and milk production of TA (Vera *et al.*, 1993). The major tropical ecosystems where meat and milk are produced are: savannah (250 million ha, 243 of them in the above-mentioned countries), tropical forest (with near 44 million ha, almost all in the same four countries (Vera *et al.*, 1993), and Andean hillsides (96 million ha, in Colombia, Ecuador, Perú and Venezuela). This area excludes the hillsides of Brazil, the hillsides of Central America, and the foothills of the Andes in Brazil, extensive areas that are essentially identical in their topography and land use to those from the Andean Hillsides in Perú, Ecuador, Colombia and Venezuela (Jones, 1993; Amézquita *et al.*, 1998).

Meat and milk production in TA have important socio-economic significance. Its consumption is high in most cities, meat and milk representing respectively 12-26% and 7-13% of total family expenditure (Rubinstein and Nores, 1980). Meat consumption per capita/year in TA ranges from 7 to 38 kg, while in other tropical regions of the world it ranges from 0.7 to 2.6 kg in Southeast Asia and from 3.6 to 9.6 kg in tropical Africa (Valdés and Nores, 1979). The positive impact of improved and well-managed pasture systems on productivity, farmers' socio-economic condition, export market competitiveness and economic development of TA's countries has been amply documented (CIAT, 1976-2000; Rubinstein and Nores, 1980; Sanint *et al.*, 1984; Toledo, 1985; Rivas *et al.*, 1998; Vera *et al.*, 1993).

Land-Use Change in Latin America

Conversion of forests to crops and pastures has been the most important land - change in TA in the last fifty years (Kaimowitz, 1996). In Colombia (Table 1) the decline in forest area has been accompanied by an increase in pasture area with no major change in cropped area, as pastures are established once soils are too degraded for crop production. However, cattle production systems are not the only cause of deforestation (Kaimowitz, 1996). Deforestation is attributed to population pressure, national policies, ease of access to the forests, high initial soil fertility with favorable conditions for crop and pasture establishment, and production and marketing interests of multinational companies searching for highly profitable timber production (Browder, 1988; Sader and Joyce, 1988; Veldkamp, 1993, 1994). After deforestation and crop and pasture establishment, many areas have been abandoned due to production decline caused by mismanagement, which has caused degradation in more than 60% of the TA's pasture area (CIAT, 1999).

Table 1. Land Use Change in Colombia 1950-2000. Area (million ha, %).

Land Use	1950 area, (%)	1970 area, (%)	1978 area, (%)	1987 area, (%)	1995 area, (%)	2000 area, (%)
Crops	5.0 (4)	7.6 (7)	8.8 (8)	5.3 (5)	4.4 (4)	5.0 (5)
Pastures	14.6 (13)	17.5 (15)	20.5 (18)	40.1 (35)	35.5 (31)	45.0 (39)
Forest	94.6 (83)	89.1 (78)	84.9 (74)	68.7 (60)	74.2 (65)	64.2 (56)
Total	114.2 (100)	114.2 (100)	114.2 (100)	114.2 (100)	114.2 (100)	114.2 (100)

Source: Ramírez y Ortiz R, 1997.

Carbon Sequestration and Land Use

Recently, there has been an increased interest in carbon sequestration worldwide. The Kyoto Protocol (Conference of the Parties in its third session, COP3, 1997) and subsequent agreements of the United Nations (COP4 to COP9, 1998-2003) considered reforestation and afforestation to be land-use systems suitable for economic incentives in developing countries through Clean Development Mechanism (CDM) and international carbon trading. Although environmental considerations might suggest that partial reforestation of areas currently under pasture could potentially contribute to carbon sequestration, this would cause a serious threat to the socio-economic welfare of farmers who derive their living from livestock activities and to food availability (especially milk and meat) for the population. Therefore, the combination of agricultural production and environmental services (particularly carbon sequestration) through improved and well-managed pasture, agro-pastoral and silvo-pastoral systems, appears to be a good alternative. Additionally, the approval for European Union countries to contribute to their greenhouse gas (GHG) emission reduction through carbon sequestration in grassland systems (Marrakech Accords, COP7, 2001) and the United States' motivation to provide farmer's incentives for carbon sequestration in grasslands (United States Department of Agriculture, June 2003) makes this alternative particularly attractive to countries in TA, as tropical pasture, agro-pastoral and silvo-pastoral systems could be also considered to be land-use systems suitable for international carbon trading and other economic incentives for developing countries.

Objective

This paper presents three-year research results on the evaluation of soil carbon stocks (SCS) in long-established pasture and silvo-pastoral systems (10-16 years under commercial production), native forests and degraded land, in four ecosystems of TA:

tropical Andean hillsides (Colombia), sub-humid tropical forest (Costa Rica), humid tropical forest (Costa Rica), and humid tropical forest, Amazonia (Colombia). Results presented in this article correspond to the first C-sampling cycle of long-established systems in all ecosystems under investigation, with fieldwork conducted in 2002 and 2003. A second C-sampling cycle of all long-established systems in all ecosystems is being carried-out at present and is envisaged to continue throughout 2005, with research results expected in 2006. Long-established systems under evaluation, due to their age, are thought to have reached equilibrium in their soil carbon accumulation capacity. Therefore, C-sampling cycles are considered 'replications in time' implemented to obtain more precise estimates of SCS, although significant differences in systems' SCS would not be expected between both C-samplings. This hypothesis will be the subject of a future research publication.

Results presented in this article are part of the research agenda of the long-term international project entitled "Research Network for the Evaluation of Carbon Sequestration Capacity of Pasture, Agro-pastoral and Silvo-pastoral Systems in the American Tropical Forest Ecosystem". The project aims at identifying pasture, agro-pastoral and silvo-pastoral systems that represent attractive economic alternatives to the farmer and show high levels of carbon sequestration and carbon stocks, comparing them with two reference states: degraded land, or degraded pasture (negative control), and native forest (positive control). In addition, it aims at providing recommendations to policy makers at local, national and international levels about appropriate pasture systems, while also considering their socio-economic benefit and provision of environmental services, particularly carbon sequestration. The project works on four contrasting ecosystems of TA: tropical Andean hillside in Colombia; sub-humid and humid tropical forest in Costa Rica; and humid tropical forest in Amazonia, Colombia, with a possible addition from 2005 onwards of the savannah ecosystem, with research sites in Colombia (Amézquita, 2002).

This paper presents results on SCS from a range of improved pasture and silvo-pastoral systems evaluated in farms' networks located in the four ecosystems mentioned above. An 'improved' pasture or silvo-pastoral system has one or more of the following characteristics: appropriate soil management, use of grass, grass-legume, or grass-legume-tree pastures with species that are more productive than local varieties, and use of appropriate plant management practices.

Methodology

Land-Use Systems and Sites for Evaluation of Soil Carbon Stocks

SCS were evaluated in long-established pasture and silvo-pastoral systems under grazing on commercial farms, 10-16 years after establishment depending on the ecosystem. Table 2 describes the range of land use systems evaluated at each ecosystem. Field research was conducted in three networks of farms located in the project ecosystems. The tropical Andean hillsides farmers' network consisted of six small farms (2-12 ha) of dual-purpose cattle production, located in two sites of the tropical Andean hillsides: Dovio, Colombia (1900 m.a.s.l., 1800 mm/yr, 14^{0}C, high slopes, pH 5.5-6.5, medium fertility soils) and Dagua, Colombia (1350 m.a.s.l., 1800 mm/yr, 20^{0}C, medium slopes, pH 5.0-6.1, less fertile soils).

Table 2: Land-Use Systems Evaluated per Ecosystem

-Tropical Andean Hillsides

Zone 1 (Dovio, Colombia)	Zone 2 (Dagua, Colombia)
1. Native Forest (positive control)	1. Native Forest (positive control)
2. Improved pasture: *Brachiaria decumbens* under grazing	2. Improved pasture: *Brachiaria decumbens* under grazing
3. Mixed Forage Bank for "cut and carrying", composed of 5 tree species: *Trichanthera gigantea, Morus spp, Erthrina edulis, Boehmeria nivea,* and *Tithonia diversifolia*	3. Mixed Forage Bank for "cut and carrying" composed of 4 species: *Trichanthera gigantea, Morus spp, Erthrina fusca* and *Tithonia diversifolia*
4. Degraded pasture (negative control): King grass (*Pennisetum purpureum* and *Pennisetum benthami) + Melinis minutiflora* pasture, degraded, overgrazed, with presence of *Psidium guajaba* tress and weed invasion (*Pteridium aquilinum* and *Sida sp.*)	4. Natural regeneration of a degraded pasture: *Hyparrhenia rufa* pasture, non-grazed, invaded by weeds such as *Andropogon bicornis, Andropogon leucostachyus, Pteridium aquilinum, Baccharis trinervis* and *Calea sp.*
	5. Secondary Forest
	6. Degraded land (negative control)

- Humid and sub-humid tropical forest, Costa Rica

Zone 1 (Pocora, Atlantic coast, humid tropical forest)	Zone 2 (Esparza, Pacific coast, sub-humid tropical forest)
1. Native Forest (positive control)	1. Native Forest (positive control)
2. Improved silvo-pastoral system: *Acacia mangium + Arachis pintoi*	2. Improved silvo-pastoral system: *Brachiaria brizantha + Cordia alliodora + Guazuma ulmifolia*
3. Improved pasture system: *Brachiaria brizantha + Arachis pintoi*	3. Improved pasture: *Brachiaria decumbens* under grazing
4. Improved pasture: *Brachiaria brizantha*	4. Native grass: *Hyparrhenia rufa*
5. Native grass: *Ischaemum ciliare*	5. Forage Bank: *Cratylia argentea*
6. Degraded pasture: *Ischaemum ciliare*, overgrazed (negative control)	6. Secondary Forest
	7. Degraded Pasture: *Hyparrhenia rufa*, overgrazed (negative control)

Table 2 (cont.): Land Use Systems Evaluated per Ecosystem

- Humid tropical forest, Amazonia, Colombia

Zone 1 ("La Guajira" farm, flat topography, Florencia, Colombia)	Zone 2 ("Pekin" farm, mild-slope topography, Florencia, Colombia)
1. Native Forest (positive control)	1. Native Forest (positive control)
2. *Brachiaria decumbens* +native legumes	2. *Brachiaria decumbens* + native legumes
3. *Brachiaria humidicola* + native legumes	3. *Brachiaria humidicola* + native legumes
4. *Brachiaria decumbens*	4. *Brachiaria decumbens*
5. *Brachiaria humidicola*	5. *Brachiaria humidicola*
6. Degraded pasture: overgrazed *Brachiaria decumbens*, invaded by weeds such as *Homolepis aturencis, Pteridium aquilinum* and *Clidemia hirta*	6. Degraded pasture: overgrazed *Brachiaria decumbens* + *Desmodium ovalifolium* + *Calopogonium muconoides* pasture, invaded by weeds such as *Imperata cilindrica, Pteridium aquilinum* and *Ciperus ferax*

The sub-humid and humid tropical forest of Costa Rica farmers' networks consisted of eight small and medium-size farms (7-92 ha), four of them located in the sub-humid tropical forest of the Pacific Coast near Esparza, Costa Rica (200 m.a.s.l., 28°C, six months of dry season and six months with 2200 mm, poor acid soils) and four in the humid tropical forest, near Pocora, Costa Rica (200 m.a.s.l., 28-35°C, 3500 mm/year, poor acid soils). The Colombian Amazonia humid tropical forest farmers' network consisted of four medium-size farms (250-500 ha) located near Florencia, Colombia (500-800 m.a.s.l., 30-42°C, 4200 mm/yr, flat or mild-slope area with slopes <10%, pH 4.2-4.6, very poor acid soils).

Soil Sampling Design for Evaluation of Soil Carbon Stocks

A soil sampling design controlling factors affecting SCS (site conditions, slope or main gradient, land-use system, and soil depth) was used. SCS were evaluated at four soil depths (0-10, 10-20, 20-40 and 40-100 cm) using two to three replications per system and twelve sampling points per system/replication. All samples were composite samples. Total C, oxidizable C, total N, P, CEC, pH, soil texture and bulk density were evaluated at each soil pit and depth. Total C, oxidizable C and stable C (the latter expressed as the difference between total C and oxidizable C) were expressed in Megagrams (tons) C/ha/depth for each soil depth. Oxidizable carbon was determined by wet oxidation according to Walkley & Black (USDA, 1996: 6A1). Total carbon was determined by dry combustion at 120 °C. CEC at pH 7 was determined by the ammonium acetate method (USDA, 1996: 5b4). pH in water was determined with a 1:5 solid: solution ratio (USDA, 1996: 8C1). Soil texture was determined by pipette method and sieving (USDA, 1996: 3A). Available P was determined according to Bray-I (USDA, 1996: 6S3).

Statistical Analysis Methodology

For statistical comparisons of SCS between land-use systems, calculations based on fixed soil mass according to Ellert *et al.* (2002) -- which adjusts SCS to a constant soil weight value per sampling point for a given soil depth-- without subdivision in soil horizons as modified by Buurman *et al.* (2004), were carried-out for total C and stable C, using ANOVA models consistent with the sampling design. Following Buurman *et al.* (2004), the minimum soil mass per sampling point to 1 m depth was used as reference for each experimental area. Although the fixed soil mass method is more accurate, many authors conveniently use fixed depth soil carbon stock estimates instead. We therefore present both estimates for our research sites. A perfect correlation between fixed soil mass and fixed soil depth estimates should be expected exclusively when bulk densities do not show a large variation with depth. The two calculation methods --fixed soil depth and fixed soil mass-- were compared in terms of absolute SCS estimates. Multivariate statistical analysis techniques, such as Principal Component Analysis and Cluster Analysis, were used to identify relationships between SCS and soil parameters and to group sampling points that were similar in their soil conditions and their level of SCS.

Initial Soil Characterization

A complete soil characterization of each land-use system at the four ecosystems considered was performed at the beginning of the project. All soil parameters described earlier were evaluated at four soil depths: 0-10, 10-20, 20-40 and 40-100 cm (Amézquita, 2003; Amézquita *et al.*, 2003).

Land-Use History

Based on verbal information given by landowners, a 50-year land-use history was recorded for each land use system evaluated. Table 3 shows this information for tropical Andean hillsides land-use systems. Similar information was recorded for land-use systems from the sub-humid and humid tropical forest ecosystems of Costa Rica and the humid tropical forest of Amazonia, Colombia (Amézquita *et al*, 2003; Amézquita *et al.*, 2004).

Socio-economic Evaluation

Socio-economic characterization of improved and conventional farms within each ecosystem was carried out through participatory workshops, field days and socio-economic surveys of farmers. The main purpose of this research is to identify pasture and silvo-pastoral systems that represent viable economic alternatives to the farmer apart from providing environmental services, particularly carbon sequestration. Research is conducted in three phases: a) characterization of improved-systems farms versus conventional-systems farms in terms of environmental and socio-economic indices; b) simulation of investment scenarios to perform cost/benefit analysis and understand the relevance for farmers to invest in carbon sequestration; and c) formulation of policy recommendations at local, national and international levels. The first phase, the characterization of improved-systems farms versus conventional-systems farms in their environmental conditions and farmers' welfare, has concluded. Environmental, life quality and socio-economic indices per farm were produced and statistically compared between the two groups of farms. Partial results are reported in the present article. A follow-up with the participating farmers to ensure that they continue to manage these systems adequately is not the subject of the present on-going research project. However, it is expected to be the central objective of a new, future research proposal.

Table 3: Land Use Change (last 50 years). Tropical Andean Hillsides.
Area 1: Dovio (1900 m.a.s.l.), Colombia

Present Land Use System	Initial Land Use	1950's	1960's	1970-1977	1977-1986	1986-1988	1988	1988-2002
Degraded Pasture	Forest	Sugar cane	Abandoned land	Fruit trees (Tomate de árbol)	Pasture *(Melinis minutiflora)*	King grass var Taiwan	Degraded King grass + trees + maize+ pineapple	Degraded King grass Pasture
Improved Pasture	Forest	Sugar cane	Coffee + Guamo	Fruit trees (Tomate de árbol)	Abandoned land	*Brachiaria decumbens* under grazing		
Mixed Forage Bank	Forest	Maize-beans-sweet-potatoes		Fruit trees + maize	Star grass	5-specie Forage Bank *Trichanthera gigantea, Morus spp, Erthrina edulis, Boehmeria nivea, Tithonia diversifolia.*		
Native Forest	Forest	Forest			Forest			

Area 2: Dagua (1350 m.a.s.l.), Colombia

Present Land Use System	Initial	1950's	1960 – 1986	1986 – 2002
Degraded Pasture	Forest	*Hyparrhenia ruffa* pasture under grazing		Degraded *Hyparrhenia rufa* pasture
Improved Pasture	Forest	Coffee	*H. rufa* pasture	*Brachiaria decumbens* under rotational grazing
Mixed Forage Bank	Forest	Coffee	*H. rufa* pasture	4-species Forage Bank *Trichanthera gigantea, Morus spp, Erthrina fusca, Tithonia diversifolia*
Native Forest	Forest	Forest		Forest

Results

Soil Carbon Stocks

Tables 4 and 5 show statistical comparisons of SCS between land use systems using fixed soil mass and fixed soil depth estimates in the tropical Andean hillsides of Colombia (Table 4) and in the sub-humid and humid tropical forest of Costa Rica (Table 5). When SCS estimates were adjusted to fixed soil mass, corresponding rankings between land use systems remained the same, but SCS estimates and statistical comparisons between systems changed, indicating an over-estimate of stocks when using fixed-depth calculations.

Table 4: Soil Carbon Stocks (Mg C/ha) per Land Use System, estimated based on fixed soil mass (Method 1) and fixed soil depth (Method 2).
Tropical Andean Hillsides, Colombia.

Zone 1: Dovio (1900 m.a.s.l.)

System	Total C (Mg/ha)		Oxid C (Mg/ha)		Stable C (Mg/ha)	
(N = 12 sampling points per land use system)	Meth 1	Meth 2	Meth 1	Meth 2	Meth 1	Meth 2
1. Native forest	234 a	262 a	169 a	184 a	67 a	79 a
2. *B. decumbens* pasture	162 b	213 b	125 b	159 b	38 b	55 ab
3. Degraded pasture	156 b	183 bc	121 b	139 c	37 b	46 ab
4. Mixed forage bank	138 b	161 c	94 c	106 d	47 b	58 b
Mean	173	209	127	151	47	58
CV (%)	22.2	21.2	15.4	14.6	48.5	47.3

Zone 2: Dagua (1350 m.a.s.l.)

System	Total C (Mg/ha)		Oxid C (Mg/ha)		Stable C (Mg/ha)	
(N = 12 sampling points per land use system)	Meth 1	Meth 2	Meth 1	Meth 2	Meth 1	Meth 2
1. Native forest	186 a	214 a	149 a	172 a	42 ab	50 b
2. Secondary forest	152 b	177 b	115 b	129 b	37 b	48 b
3. Nat. regen. of degr. pasture (Fallow land)	147 b	171 b	89 c	93 c	59 a	78 a
4. *B. decumbens* pasture	142 b	165 b	118 b	141 b	35 b	42 b
5. Degraded land	97 c	125 c	62 d	71 d	35 b	54 b
6. Mixed forage bank	86 c	104 d	60 d	68 d	26 b	36 c
Mean	135	159	99	112	39	51
CV (%)	27.9	27.9	15.6	13.7	56.4	55.4

Source: Amézquita *et al.* (2003)

Table 4 shows that for zone 1 (Dovio), with higher altitude, steeper slopes and higher relative fertility, native forest (234 Mg/ha/1m-equivalent) had statistically higher stocks than improved *B. decumbens* pasture, degraded pasture, and mixed-forage bank for cut and carrying (162, 156 and 138 Mg/ha/1m-equivalent, respectively). On zone 2 (Dagua), with lower altitude, less inclined slopes and lower fertility, lower levels of SCS were found for all systems. Native forest (186 Mg/ha/1m-equivalent) had statistically higher stocks than secondary forest, natural regeneration of a degraded pasture and improved *B. decumbens* pasture (152, 147 and 142 Mg/ha/1m-equivalent, respectively, non-statistically different), which in turn had statistically higher stocks than degraded soil and mixed forage bank for cut and carrying (97 and 86 Mg/ha/1m-equivalent, respectively). Although native forest possesses the highest soil carbon accumulation capacity in this ecosystem, improved pasture systems and natural regeneration systems (fallow land and secondary forest) seem good environmental solutions for the recovery of degraded areas, as C-improved systems.

Table 5: Soil Carbon Stocks (Mg C/ha) per Land Use System, estimated based on fixed soil mass (Method 1) and fixed soil depth (Method 2). Humid and Sub-humid Tropical Forest, Costa Rica.

Zone 1: Pocora, Atlantic Coast, Humid Tropical Forest

System	**Total C (Mg/ha)**		**Oxid C (Mg/ha)**		**Stable C (Mg/ha)**	
(N = 12 sampling points per land use system)	Meth 1	Meth 2	Meth 1	Meth 2	Meth 1	Meth 2
1. *I. ciliare* pasture	208 a	212 a	182 a	186 a	26 a	27 a
2. *B. brizantha+A. pintoi*	194 a	202 a	166 b	172 a	28 a	27 a
3. *A. mangium+A. pintoi*	168 b	173 b	135 c	139 a	33 a	34 a
4. *B. brizantha*	134 c	135 c	120 cd	120 c	15 b	15 b
5. Native forest	128 c	128 c	111 d	111 c	17 b	17 b
6. Degraded pasture	94 d	101 d	84 e	90 d	10 b	11 b
Mean	159	158	135	136	22	22
CV (%)	27.0	26.8	17.0	18.1	49.4	48.7

Zone 2: Esparza, Pacific Coast, Sub-humid Tropical Forest

System	**Total C (Mg/ha)**		**Oxid C (Mg/ha)**		**Stable C (Mg/ha)**	
(N = 12 sampling points per land use system)	Meth 1	Meth 2	Meth 1	Meth 2	Meth 1	Meth 2
1. Native forest	185 a	194 a	171 a	180 a	14 a	15 ab
2. *H. rufa pasture*	169 a	180 a	153 a	162 ab	16 a	18 ab
3. *B. decumbens* pasture	134 a	137 a	104 a	106 ab	30 a	31 a
4. Forage bank	130 a	133 a	117 a	117 ab	14 a	14 ab
5. Silvo-pastoral system	130 a	132 a	112 a	119 ab	18 a	14 ab
6. Degraded pasture	129 a	195 a	117 a	126 ab	11 a	11 b
7. Secondary forest	116 a	116 a	101 a	101 b	15 a	15 ab
Mean	143	155	128	131	16	17
CV (%)	25.2	24.3	23.3	21.2	45.4	42.9

Source: Llanderal and Ibrahim (2004)

Table 5 shows that for zone 1 (Pocora), a humid tropical forest on the Atlantic coast with a humid environment year round, pasture systems such as *I. ciliare*, *B. brizantha* + *A.*

pintoi, *A. mangium* + *A. pintoi* and *B. brizantha* in monoculture (208, 194, 168 and 134 Mg/ha/1m-equivalent, respectively) had statistically higher stocks than native forest (128 Mg/ha/1m-equivalent), which in turn had statistically higher stocks than degraded pasture (94 Mg/ha/1m-equivalent). Similar rankings were obtained in the humid tropical forest of Amazonia, Colombia, where *B. humidicola* and *B. decumbens* pastures (monoculture and legume-associated) showed higher SCS than native forest (data not shown in the present paper). In zone 2 (Esparza) -- sub-humid tropical forest on the Pacific coast, with six months of severe dry season -- no statistical differences were found between land-use systems in their SCS level expressed either as total carbon, oxidizable carbon or stable carbon (Table 5). In hot and humid environments improved pasture systems show SCS comparable or higher than native forest, therefore representing attractive environmental solutions for the recovery of degraded areas as C-improved systems.

Results of Multivariate Analysis

Principal Component Analysis and Cluster Analysis were used to identify relationships between SCS and soil parameters and to group sampling points with similar soil conditions and SCS level. Table 6 shows results of the tropical Andean hillsides ecosystem. Principal Component Analysis allowed for the reduction of soil and carbon parameters to two main principal components. They explained 39% and 28%, respectively -- 67% combined -- of the total variance present in the original variables. Principal component 1 (39% of the total variance) suggests a positive association of total carbon and total N with predominance of sand over clay. Principal component 2 (28% of the total variance) suggests a positive association of stable carbon with predominance of clay over sand.

Table 6: Association between Soil and Carbon variables.
Principal Component Analysis.

Variable	PC_1 (39%)	PC_2 (28%)
	- Principal Components' Scores -	
Total C (Mg/ha/1m-equivalent)	0.47	0.43
Total N (Mg/ha/1m-equivalent)	0.46	0.31
Stable C (Mg/ha/1m-equivalent)	0.15	0.56
Sand (Mg/ha/1m-equivalent)	0.49	-0.32
Clay (Mg/ha/1m-equivalent)	-0.50	0.32
pH (mean in 1m-equivalent)	0.12	0.12
CEC(meq) (mean in 1m-equivalent)	0.24	-0.38

Cluster Analysis, using as classification criteria the two first principal components resulting from the previous analysis, allowed for the grouping of sampling points with similar soil conditions and soil carbon stock levels. Six groups were obtained explaining 77 % of the total variability among sampling points. Characterization of cluster groups presented in Table 7, suggests that although land use system and site conditions seem to be the most important factors determining SCS, other factors not considered in this study play an important role in soil carbon accumulation, such as prior land-use history of each field.

Table 7: Soil Carbon Stocks by Cluster (93 Sampling points, 6 Clusters)

Cluster	Total C (Mg/ha/1m-equiv) Min-Max (Mean)	Stable C (Mg/ha/1m-equiv) Min-Max (Mean)	Sampling Points in the Cluster
1 (N=5)	300-374 (335)	66-131 (86)	Forest Zone 1 (3) Forest Zone 2 (2)
2 (N= 8)	203-287 (248)	23-108 (68)	Forest Zone 1 (3) Forest Zone 2 (3) Improved pasture Zone 1 (1) Improved pasture Zone 2 (1)
3 (N=30)	152-299 (211)	23-129 (68)	All points belong to Zone 1 Forest (5), Imp past (11), Degr. past (9), Forage Bank (8)
4 (N=21)	118-239 (171)	23-148 (72)	All points belong to Zone 2 Improved pasture (9) Degraded pasture (12)
5 (N=6)	171-192 (160)	8-52 (24)	Forest Zone 1 (1) Forest Zone 2 (5)
6 (N=23)	70-171 (124)	7-71 (34)	Forage Bank Zones 1,2 (13) Degr. past Zone 1 (6) Impr. past Zone 2 (2) Forest Zone 2 (2)

Socio-economic indicators

In order to compare improved versus conventional farms in their provision of environmental services and socio-economic benefit to the farmer, environmental and socio-economic indicators were estimated per farm for the four ecosystems. Table 8 shows that for the tropical Andean hillsides of Colombia, improved-systems farms perform statistically better than conventional-systems farms, both in environmental conditions, such as percent area forested and percent area in improved systems, and in socio-economic conditions, such as farm gross income/ha/year, farmer self-sufficiency, family living conditions, and educational level.

Table 8. Socio-Economic Indices of Improved *vs.* Conventional farms
Tropical Andean Hillsides, Colombia

Index	Farm Type		
	Improved (n=6)	Conventional (n=19)	p
1. Farm area in forest (%)	29	14	**
2. Farm area improved systems (%)	88	44	**
3. Farm gross income/ha/yr (US$)	250	50	***
4. Farmer self-sufficiency (%)	40	32	*
5. Living conditions (1–5)	5	3	**
6. Educational level			
• Adult literacy (%)	79	76	*
• Mean years of schooling	8	6	*

p = Probability of statistical significance; * : $0.05<p<0.10$; ** : $0.01<p<0.05$; *** : $p<0.01$

Conclusions

1. In the tropical ecosystems of Latin America studied in the present research, improved pasture and silvo-pastoral systems show SCS levels comparable or even higher than those from native forest, depending on climatic and environmental conditions (altitude, temperature, precipitation, topography and soil). Therefore, these systems should be considered as attractive and viable C-improved systems.

2. Carbon sequestration research requires the use of a proper methodology for field evaluation and mathematical estimation of soil carbon stocks. The following factors should be taken into account (a) a soil sampling design taking into account factors affecting SCS needs to be used to obtain minimum-variance estimates; (b) variability of SCS estimates depends on land-use type (i.e., higher variability on degraded pasture systems, characterized by a high heterogeneity in vegetation, than on improved grass-alone systems or silvo-pastoral systems with less heterogeneity in vegetation),site conditions (altitude, climate, topography), soil characteristics, and carbon fraction; (b) for statistical comparisons of land-use systems, SCS estimates corrected by bulk density and adjusted to fixed soil mass per sampling point should be used, which are more precise than those based on fixed soil depth calculations; (c) SCS estimates for a given land-use system need to be interpreted based on long-term land --use history.

3. Tropical pasture and silvo-pastoral systems are important socio-economic components of the economies of Tropical America's countries, across all ecosystems. When improved and well managed, they can become key land-use systems for the provision of environmental services, particularly the recovery of degraded areas and carbon sequestration. In addition, they have the capacity to provide viable economic alternatives to farmers.

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Annex 3

Project Scientific Publication no. 2

"Carbon Sequestration Potential of Pasture and Silvo-pastoral Systems in the Tropical Andean Hillsides"

By M.C. Amézquita, P. Buurman, E. Murgueitio
and E. Amézquita

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Carbon Sequestration Potential of Pasture and Silvo-pastoral Systems in the Tropical Andean Hillsides[1]

M. C. Amézquita[2], *P. Buurman*[3], *E. Murgueitio*[4] *and E. Amézquita*[5]

Abstract

The Tropical Andean Hillsides Ecosystem comprises 96 million ha in Perú, Ecuador, Colombia and Venezuela. It constitutes the highest population density in Tropical America (TA) representing only 6% of TA's area. Both, population pressure and poverty in the small-farmers sector cause severe deforestation of steep slopes. Pasture, agro-pastoral and agro-silvo-pastoral systems, providers of milk and meat, have important socio-economic significance. Preliminary research suggests that improved and well-managed pasture systems constitute a solution to poverty reduction, recovery of degraded areas and delivery of environmental services, in particular carbon sequestration. This article presents 3-year research results generated by the "Carbon Sequestration Project, The Netherlands Cooperation CO-010402" on soil carbon stocks (SCS) from a range of long-established pasture and silvo-pastoral systems prevalent in the Tropical Andean Hillsides, compared to native forest (positive control) and degraded land (reference control). Based on research-generated SCS and system's age, carbon sequestration rates (Mg of total organic C/ha/year, measured at 1m of soil depth) were calculated for the different land use systems with the assumption that the system was converted from degraded land. Carbon sequestration rates from two contrasting research sites in the Tropical Andean Hillsides of Colombia show that *Brachiaria decumbens* with trees (5.5 and 2.9 Mg/ha/year for sites 1 and 2, respectively) had higher or similar rates than natural regeneration of a degraded pasture (3.6 and 2.9 Mg/ha/year for sites 1 and 2, respectively) and higher rates than a 50-year old non-intervened natural forest (2.7 and 1.8 Mg/ha/year for sites 1 and 2, respectively). Based on research-generated rates and expert knowledge on land use and degradation, a first approximation of the potential for carbon sequestration of the Tropical Andean Hillsides, considering the best C-sequestration option for each type of degraded area over a 20-year period, was estimated as $3.7*10^{15}$ g C.

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I. Introduction

A. Tropical America

Tropical America (TA) comprises Mexico, Central America, The Caribbean, and South America, excluding Argentina, Chile and Uruguay. It holds 8% of the world's population, 11% of the world's continental area, 23% and 22%, respectively, of the world's forest and water resources --with a per capita water availability of 35,405 m^3 almost 5 times the corresponding world average--, 21% of the world's cattle inventory and 13% of the world's pasture and agro-pastoral land. These land uses represent 77% of TA's agricultural land. Pastures:crop land ratio of 3.4 is higher than the world ratio of 2.3 (FAO, 2000; Table 1).

Milk and meat in TA's countries have important socio-economic significance (Rubinstein and Nores, 1980). The annual per capita meat consumption in TA ranges from 7 to 38 kg compared with 0.7 to 2.6 kg in Southeast Asia and 3.6 to 9.6 kg in tropical Africa (Valdés and Nores, 1979). High income elasticity for beef and dairy products throughout TA at all income levels has been documented. Increase in supply of meat and milk will benefit the poor (Toledo, 1985; Vera *et al.*, 1993; Rivas *et al.*, 1998). The effect of improved and well-managed pasture systems on increase in productivity, socio-economic benefit, export market competitiveness and economic development of TA's countries has been amply documented (CIAT, 1976-1996; CIAT, 1999; Rubinstein and Nores, 1980; Sanint *et al.*, 1984; Toledo, 1985; Vera *et al.*, 1993; Rivas *et al.*, 1998). The major tropical ecosystems where meat and milk are produced are the Savannah Ecosystem (250 million ha), the Tropical Forest Ecosystem (about 44 million ha) and the Tropical Andean Hillsides Ecosystem (96 million ha) (Vera *et al.*, 1993, Amézquita *et al.*, 1998).

B. The Tropical Andean Hillsides Ecosystem

The Andean Mountain Chain (Cordillera de Los Andes) is the longest mountain complex on Earth. Located in the western part of South America, parallel to the Pacific coast, it has a total length of 7200 km from Cabo de Hornos, Argentina, to the Caribbean Sea in Venezuela. It has a minimum width of 100 km in the southern part, a maximum width of 600 km in the central part of the continent between Perú and Bolivia, and a mean width of 241 km. Its mean altitude is 3660 m.a.s.l. and the maximum altitude is 6959 m.a.s.l. at the Aconcagua peak in Argentina (Encarta, 2003; Kindersley, 2004). Consequently, the region exhibits a wide range of climatic conditions, landscapes, hydrology, hydrological cycles and biodiversity. In the central part of South America the Andean Mountain divides into two chains that cross Perú and Ecuador (Central and Eastern Mountain), and into three chains in Colombia (Western, Central and Eastern Mountain) forming inter-Andean valleys of flat lands with high available water and soil fertility.

Table 1: Population, land resources, agricultural and livestock production in 2000 in tropical America and the world.

Resources	Tropical LA [1]	Temperate LA [2]	Total LA	World
1. Population				
• Total, millions of people (world %)	431.5 (7.5)	52.8 (0.9)	484.3 (8.4)	5757.8 (100.0)
• In agric., millions of people (world %)	100.3 (3.9)	2.5 (0.1)	102.8 (4.0)	2592.4 (100.0)
• % population in agriculture in the region	23.24	4.73	21.85	45.02
2. Land resources and land use				
• Total continental land [3], million ha (world %)	1688 (11.3)	371 (2.5)	2059 (13.7)	14991 (100.0)
• Agricultural land, millions ha (world %)	548 (11.3)	201 (4.1)	749 (15.4)	4866 (100.0)
• Pastures, million ha (world %)	424 (12.5)	169 (5.0)	593 (17.4)	3399 (100.0)
• % pasture within agric.land in the region	77.37	84.08	79.17	69.85
• Crops, millions of ha (world %)	124 (8.5)	32 (2.2)	156 (10.6)	1467 (100.0)
• % crops within agric. land in the region	22.63	15.92	20.83	30.15
• Pastureland /cropland ratio in the region	3.42	5.28	3.80	2.32
* Forest land, millions of ha (world %)	938 (22.5)	68 (1.6)	1006 (24.1)	4172 (100.0)
• % of forest land in the region	41.32	18.38	38.11	27.83
3. Water resources				
• Total, km^3 (world %)	9005 (22.0)	1586 (3.9)	10591 (25.8)	41002 (100.0)
Per capita, m^3 (region/world ratio)	35405 (4.9)	30479 (4.3)	34831 (4.9)	7176.8 (1.0)
4. Cattle inventory				
• Total, million heads (world %)	280 (21.2)	68 (5.2)	348 (26.4)	1320 (100.0)
Lactating cows, million heads (world %)	41 (17.9)	4 (1.8)	45 (19.7)	229 (100.0)
• % of lactating cows in the region	14.64	5.88	12.93	17.35
5. Meat and milk production				
• Meat, million metric tons (world %)	9 (16.7)	3 (5.6)	12 (22.2)	54 (100.0)
• Milk, million metric tons (world %)	42 (9.0)	12 (2.6)	54 (11.6)	466 (100.0)

SOURCE: FAO (2000); Rivas *et al.* (1998).

[1] Mexico, Central America, The Caribbean, and South America, excluding Argentina, Chile and Uruguay.

[2] Argentina,Chile and Uruguay. [3] Original data expressed in millions km^2 (Nieuwe Grote Wereldatlas, 1977).

The Tropical Andean Hillsides occupy 96 million ha from southern Perú, at 7° S, to Sierra Nevada de Santa Martha in Colombia, at 12° N. This region excludes Brazil, which also has a large area corresponding to the hillside environment (Jones, 1993), the hillsides of Central America, and the foothills of the Andes in Brazil, areas which are essentially identical (Amézquita *et al.*, 1998). The region is characterised by a very high population density and anthropogenic perturbations. In Colombia, for example, 70% of the country's total population lives in the Andean Region, with 78 inhabitants/km^2 compared to 29/km^2 in the rest of the country (DANE, 1996) comprising a rural population density of 21 inhabitants/km^2 compared to 8.4 inhabitants/km^2 in the rest of the country (Etter and Wyngaarden, 2000). About 70% of the Andean Hillsides area in Colombia is strongly influenced by human activity (Instituto Alexander von Humboldt, 1998). A similar situation holds for Andean Hillside areas in Perú, Ecuador and Venezuela (Amézquita *et al.*, 1998). The region is characterised by poverty in the small farm sector, which leads to the deforestation of steeply sloping lands which are highly vulnerable to degradation and only marginally suited to production of semi-subsistence crops (Pachico *et al.*, 1994).

II. Land Use Change, Soil Degradation and Carbon Sequestration in the Tropical Andean Hillsides

Conversion of forests to crops and pastures has been the most important land use change in TA, and in the Tropical Andean Hillsides in particular, during the second half of the 20th century (Kaimowitz, 1996). Deforestation is attributed to population pressure, national policies, ease of access to the forests, high initial soil fertility with favourable conditions for crop and pasture establishment, and production and marketing interests of multinational companies (Browder, 1988; Sader and Joyce, 1988; Veldkamp, 1993 and 1994). After deforestation and crop and pasture establishment large areas are abandoned due to decline in productivity caused by mismanagement, leading to degradation of more than 60% of the TA's pasture area, and about 90% of the Tropical Andean Hillside's pasture area (CIAT, 1999; CIAT, 1999-2001). The data in Table 2 shows a 50-year history of land use change (1950's -2000's) for some small farms in two regions of the Tropical Andean Hillsides in Colombia (Amézquita *et al.*, 2003). The Tropical Andean Hillsides are presently characterized by land use patterns of native forest, pasture systems, crops [intensive coffee production, fruit production and various annual crops such as maize (*Zea mays*), beans (*Phaseolus spp*) and cassava (*Manihoc esculenta*)] and natural regeneration areas (secondary forest and fallow land -"rastrojos"-) each with variable degree of degradation (Table 3). Pasture systems are important in the region. The data in Table 4 illustrates the predominance of pasture systems at micro-watershed level in the Andean Hillsides of Colombia, between 800-2000 m.a.s.l. (Gómez, 2002). Two types of cattle production systems are predominant: dual-purpose cattle for milk and beef production, at 1000-2000 m.a.s.l., and beef production in the lower areas, below 1000 m.a.s.l. Dual-purpose cattle production is practiced irrespective of soil, altitude or topographic conditions, in small farms (1-12 ha) of subsistence agriculture, medium-size farms (13-50 ha) and large commercial farms (50-500 ha) of agro-industrial production (Murgueitio, 2003).

Table 2: Land use change between 1950 and 2002 in the Tropical Andean Hillsides.

Area 1: Dovio (1900 m.a.s.l.), Colombia[1]

Present Land Use	Initial Land Use	1950's	1960's	1970-1977	1977-1986	1986-1988	1988	1988-2002
Degraded Pasture	Forest	Sugar cane	Abandoned land	Fruit trees (Tomate de árbol)	Pasture *(Melinis minutiflora)*	King grass var Taiwan	Degraded King grass + trees + maize+ pineapple	Degraded King grass Pasture
Improved Pasture	Forest	Sugar cane	Coffee + Guamo	Fruit trees (Tomate de árbol)	Abandoned land	*Brachiaria decumbens* with various trees under grazing		
Mixed Forage Bank	Forest	Maize-beans-sweet-potatoes		Fruit trees + maize	Star grass	5-specie Forage Bank *Trichanthera gigantea, Morus spp, Erthrina edulis, Boehmeria nivea, Tithonia diversifolia.*		
Forest	Forest	Forest (intervened)			Forest (non intervened)			

Area 2: Dagua (1350 m.a.s.l.), Colombia

Present Land Use	Initial	1950's	1960 – 1986	1986 – 2002
Degraded Pasture	Forest	*Hyparrhenia ruffa* pasture under grazing		Degraded *Hyparrhenia rufa* pasture
Improved Pasture	Forest	Coffee	*H. rufa* pasture	*Brachiaria decumbens* with trees under grazing
Mixed Forage Bank	Forest	Coffee	*H. rufa* pasture	4-species Forage Bank *Trichanthera gigantea, Morus spp, Erthrina fusca, Tithonia diversifolia*
Forest	Forest	Forest (intervened)		Forest (regenerated)

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[1] Research areas in the Tropical Andean Hillsides, Colombia. Carbon Sequestration Project, The Netherlands Cooperation C0-010402 (Amézquita *et al*, 2003).

Of the total 92 million ha corresponding to the non-urban part of the Tropical Andean Hillsides, about 20 million ha (22%) are already highly degraded and an estimated 50 million (55%) are prone to rapid degradation (Amézquita *et al.*, 1998). Expert knowledge on land use distribution and degradation levels (Table 3) is consistent with these statistics. More than 80% of the Tropical Andean Hillside area exhibits different states of erosion. The World Map on the Status of Human-induced Soil Degradation and its corresponding report (Oldeman *et al.*, 1990) indicate water erosion as the main limiting factor in the Tropical Andean Hillsides, with loss of topsoil, terrain deformation and mass movement. Also moderate to strong chemical deterioration caused by loss of nutrients and organic matter is present. Wind erosion does not occur.

Table 3. Approximate land use distribution and degradation stage in The Tropical Andean Hillsides [1]

Land Use	**Area %**	**Area million ha**	**Degradation Stage**					
			Severe		**Moderate**		**Non-degr**	
			%	million ha	%	million ha	%	million ha
Pasture systems	50	46.0	20	9.2	70	32.2	10	4.6
Crops	25	23.0	25	5.8	60	13.8	15	3.5
Native Forest (non-intervened)	13	12.0	0	0.0	0	0.0	100	12.0
Secondary Forest (intervened)	7	6.4	30	1.9	60	3.8	10	0.6
Fallow land ("rastrojo")	5	4.6	80	3.7	20	0.9	0	0.0
Total	100	92.0	22.4	20.6	55.0	50.7	22.6	20.7

Source: Expert knowledge.

[1] Excludes urban areas and other uses (mines, recreation areas, natural parks and lakes).

Table 4. Land use distribution at micro-watershed level in The Tropical Andean Hillsides, Colombia (800-2000 m.a.s.l.)

Land Use	**Micro-watershed**		
	(1) Alto Dagua – La Cumbre –Restrepo	**(2) Alto Garrapatas**	**(3) Pance-Meléndez – Cali – Aguacatal**
Pastures	53.5 (62%)	53.1 (47%)	18.3 (61%)
Crops	18.5 (22%)	26.5 (23%)	1.5 (5%)
Forest & Nat. regen.	12.9 (15%)	34.4 (30%)	8.3 (28%)
Other uses*	1.2 (1%)	0.18 (0.1%)	1.9 (6%)
Total area studied (thousand ha)	86.1 (100%)	114.2 (100%)	30.0 (100%)

Source: Gómez (2002)

*Other uses: mines, recreation areas, natural parks, lakes, urban areas.

Interest in carbon sequestration has arisen since 1990s. The Kyoto Protocol (United Nations Framework Convention on Climate Change in its third session, COP3, 1997) and subsequent agreements of the United Nations (UNFCCC COP4-COP9, 1998-2003) have considered reforestation and aforestation as suitable land use systems for economic incentives in developing countries through Clean Development Mechanism (CDM) and trading carbon credits. Although environmental considerations may suggest partial reforestation of areas currently under pasture, thus potentially contributing to carbon sequestration, this would cause a serious threat to the economic welfare of farmers and to food availability for the population, especially for milk and meat.

As a pilot project, we investigated the potential for carbon sequestration in a number of pasture, agro-pastoral and silvo-pastoral systems in various sub-ecosystems of TA, including the Tropical Andean Hillsides in two contrasting zones of the Colombian Andean Region (Amézquita, 2002).

III. Research on Carbon Sequestration in the Tropical Andean Hillsides

The present article reports results of three-year research on the evaluation of soil carbon stocks (SCS) carried-out in the Tropical Andean Hillsides as part of the research agenda of the international project "Research Network for the Evaluation of Carbon Sequestration Capacity of Pasture, Agro-pastoral and Agro-silvo-pastoral Systems in the American Tropical Forest Ecosystem", sponsored by The Netherlands Cooperation as Activity CO-010402, and implemented by CIPAV (Center for Research on Sustainable Agricultural Production Systems, Cali, Colombia), Universidad de la Amazonia (Florencia, Colombia), CIAT (International Center for Tropical Agriculture, Cali, Colombia), CATIE (Centro Agronómico Tropical para Capacitación y Enseñanza, Turrialba, Costa Rica) and WUR (Wageningen University and Research Center, The Netherlands). The project aims at identifying pasture, agro-pastoral and agro-silvo-pastoral systems which present an attractive economic alternative to the farmer and show high levels of carbon sequestration and carbon stocks, comparing them with two reference states: degraded land (reference control) and native forest (positive control). It also aims at providing recommendations to policy makers at local, national and regional level, about appropriate pasture systems considering their socio-economic benefit and provision of environmental services, particularly carbon sequestration. The project works on four contrasting sub-ecosystems of the American Tropics: Tropical Andean Hillsides, Colombia; Sub-humid and Humid Tropical Forest, Costa Rica; and Humid Tropical Forest, Amazonia and Colombia, with a possible addition from 2005 onwards of the Savannah ecosystem (Amézquita, 2002; Amézquita *et al.*, 2004).

This paper reports methodology and preliminary research findings on SCS from two contrasting experimental areas in the Tropical Andean Hillsides of Colombia, whose generalisation domain corresponds to specific environmental characteristics of 800-2000 m.a.s.l., acid soils (pH between 5.2 and 6.2), mean temperature between 14.0 and 23.5°C during the growing season, mean rainfall between 1500 and 1900 mm/year exceeding

60% of potential evapotranspiration during 6-9 months annually, and moderate to steep slopes (15-83% depending on land use system). Regions with these characteristics cover 30 million ha in Perú, Ecuador, Colombia and Venezuela. (Pachico *et al.*, 1994).

A. Methodology

SCS were evaluated in long-established pasture and silvo-pastoral systems (14-16 years) on small farms belonging to the "Network of small farmers of the Andean Hillsides of dual-purpose cattle under cut and carrying" used by research purposes by CIPAV (6 small farms of 2-12 ha/farm, located in areas representative of the above-mentioned conditions) (Amézquita, 2002). A soil sampling design taking into consideration factors affecting SCS (site conditions, slope gradient, land use, and soil depth) was used. Soil carbon contents were measured for four soil depths (0-10, 10-20, 20-40, 40-100cm) using 2 space replications per land use system and 12 sampling points/land use system/space replication. All soil samples taken were composite samples, and analyzed for bulk density, total C, oxidisable C, total N, P, CEC, pH and soil texture, for each soil pit and depth. Total, oxidisable and stable C (the later expressed as the difference between total C and oxidisable C) were corrected by bulk density and expressed as Mg C/ha in 10cm soil layers, and for 0-40, 40-100, and 0-100cm depth. Oxidisable carbon was determined by wet oxidation according to Walkley & Black (USDA, 1996: 6A1). Total carbon was determined by dry combustion at 120 °C. CEC at pH 7 was determined by the ammonium acetate method (USDA, 1996: 5b4). pH in water was determined with a 1:5 solid:solution ratio (USDA, 1996: 8C1). Soil texture was determined by pipette method and sieving (USDA, 1996: 3A). Available P was determined according to Bray-I (USDA, 1996: 6S3).

For statistical comparisons of SCS among land use systems, calculations based on fixed soil mass according to Ellert *et al.* (2002), but without subdivision in layers as modified by Buurman *et al.* (2004) were carried-out for total and stable C, using ANOVA models consistent with the sampling design. Following Buurman *et al.* (2004), the minimum soil mass per sampling point to 1 m depth was used as reference for each experimental area. Although the fixed soil mass method is more accurate, many authors conveniently use fixed depth SCS estimates instead. We therefore present both estimates for these research sites. A perfect correlation between fixed soil mass and fixed soil depth estimates is expected exclusively when bulk densities do not show a large variation with depth. The two calculation methods --fixed soil depth and fixed soil mass-- were compared in terms of absolute SCS estimates and statistical significance of land use systems comparisons.

B. Soil Carbon Stock Data

The data in Table 5 shows statistical comparisons of SCS among land use systems using fixed soil depth (Mg total organic C/ha/1m) and fixed soil mass estimates (Mg total organic C/ha/1m-equivalent). When SCS estimates were adjusted to fixed soil mass, corresponding rankings among land use systems remained the same, but absolute SCS estimates and statistical comparisons among pairs of systems changed, indicating an over-estimate of stocks when using fixed-depth calculations.

Fixed soil mass-based SCS estimates presented in Table 5 show the following. For area 1 (Dovio) --with higher altitude, more steep slopes and higher soil fertility-- native forest (234 Mg/ha/1m-equivalent) had statistically higher SCS than improved *Brachiaria decumbens* pasture with trees, natural regeneration of a degraded pasture, and mixed forage bank for cut and carrying (162, 156 and 138 Mg/ha/1m-equivalent, respectively). On area 2 (Dagua) --with lower altitude, less steep slopes and lower soil fertility--, lower levels of SCS were measured for all systems. Native forest (186 Mg/ha/1m-equivalent) had statistically higher SCS than secondary forest, natural regeneration of a degraded pasture and *B. decumbens* pasture with trees (152, 147 and 142 Mg/ha/1m-equivalent, respectively) and these in turn were statistically higher than those of degraded soil and mixed forage bank for cut and carrying (97 and 86 Mg/ha/1m-equivalent, respectively).

Table 5: Soil carbon stocks for land use system at 1m, estimated based on fixed soil mass (Method 1) and fixed soil depth (Method 2). Tropical Andean Hillsides, Colombia [1]

Area 1: Dovio (1900 m.a.s.l.)

Land Use System	Total C (Mg/ha)		Oxidisable C (Mg/ha)		Stable C (Mg/ha)	
N = 12 sampling points/system	**Meth 1**	**Meth 2**	**Meth 1**	**Meth 2**	**Meth 1**	**Meth 2**
1. Native Forest	234 a	262 a	169 a	184 a	67 a	79 a
2. *B. decumbens* with trees	162 b	213 b	125 b	159 b	38 b	55 ab
3. Nat. reg. of degr. past	156 b	183 bc	121 b	139 c	37 b	46 ab
4. Mixed Forage Bank	138 b	161 c	94 c	106 d	47 b	58 b
Mean	173	205	127	147	47	60
F-value [2]	14.5**	12.1**	29.6**	28.3**	24.9**	3.0*
CV (%)	22.2	21.2	15.4	14.6	48.5	47.3

Area 2: Dagua (1350 m.a.s.l.)

Land Use System	Total C (Mg/ha)		Oxidisable C (Mg/ha)		Stable C (Mg/ha)	
N = 12 sampling points/system	**Meth 1**	**Meth 2**	**Meth 1**	**Meth 2**	**Meth 1**	**Meth 2**
1. Native Forest	186 a	214 a	149 a	172 a	42 ab	50 b
2. Secondary Forest	152 b	177 b	115 b	129 b	37 b	48 b
3. Nat. reg. of degr. Past.	147 b	171 b	89 c	93 c	59 a	78 a
4. *B. decumbens* with trees	142 b	165 b	118 b	141 b	35 b	42 b
5. Degraded land	97 c	125 c	62 d	71 d	35 b	54 b
6. Mixed Forage Bank	86 c	104 d	60 d	68 d	26 b	36 c
Mean	135	159	99	112	39	51
F-value [2]	10.9**	9.7**	49.0**	84.9***	2.9*	4.8*
CV (%)	27.2	27.9	16.4	13.7	54.3	55.4

[1] Research areas in the Tropical Andean Hillsides, Colombia. Carbon Sequestration Project, The Netherlands Cooperation C0-010402 (Amézquita *et al.*, 2003).

[2] ***: Statistically significant with p < .001; **: significant with .001<= p <.01; *: significant with p < .05

The SCS data suggest that although native forest is characterized by the highest soil carbon accumulation capacity in this ecosystem, improved pasture systems and natural regeneration (fallow land and secondary forest) are promising environmental solutions for the recovery of degraded areas, as SCS-improved systems.

C. Carbon Sequestration Rates

Carbon sequestration rates (Mg of total organic C/ha/year) were calculated for each long-established land use system based on their corresponding SCS and duration, with the assumption that the system was converted from degraded land. For reasons of compatibility with other researchers, SCS estimates used for calculating carbon sequestration rates were based on fixed soil depth estimates, expressed as Mg total organic C/ha/1m (Table 6).

Table 6: Carbon sequestration rates (Mg total organic C/ha/yr) for different land use systems if converted from degraded land. Tropical Andean Hillsides, Colombia [1]

Area 1: Dovio (1900 m.a.s.l.)

Land Use System	System's Age (yrs)	SCS (Mg/ha/1m)	C-seq rate (Mg/ha/year)
Degraded land (reference) [2]	16	125	0
Forage bank for "cut and carrying"	16	161	2.3
Nat. regen. of degr. past.(Fallow land)	16	183	3.6
B. decumbens pasture with trees	16	213	5.5
Native forest	.> 50	262	2.7 [3]

Area 2: Dagua (1350 m.a.s.l.)

Land Use System	System's Age (yrs)	SCS (Mg/ha/1m)	C-seq rate (Mg/ha/year)
Degraded land (reference)	16	125	0
Forage bank for "cut and carrying"	16	104	-1.3
B. decumbens pasture with trees	14	165	2.9
Nat. regen. of degr. past.(Fallow land)	16	171	2.9
Secondary forest	25	177	2.1
Native forest	> 50	214	1.8 [3]

[1] Research areas, Tropical Andean Hillsides, Colombia. Carbon Sequestration Project, The Netherlands Cooperation C0-010402 (Amézquita *et al.*, 2003).

[2] SCS data of the "Degraded Land" system from Dagua (area 2) was used as reference for calculating soil carbon sequestration rates for the various land use systems in both areas.

[3] Age of non-intervened forest was assumed to be 50 years.

IV. The Soil Carbon Sequestration Potential in the Tropical Andean Hillsides

Soil carbon sequestration rates (Mg total organic C/ha/year) were calculated within the SCS estimates and system's age for the range of land use systems shown in Table 6. These, together with expert knowledge on land use area and degradation level (Table 3) allowed a first approximation of carbon sequestration potential for the Tropical Andean Hillsides (Table 7).

Table 7: Soil carbon sequestration potential of the Tropical Andean Hillsides over a 20-year period: A first Approximation[1]

Present Land Use	Optional Land Use (C-improved)	Potential area to be converted to option		Soil C-seq. rate (Mg/ha/ year)	Soil C-seq potential /ha under each option (Mg/ha/20 years)	Total soil C-seq potential under each option over a 20-year period (10^{15} g C)
		%	mill. ha			
1. Degraded Land	1.Nat. reg of degr. Land	22.4	20.6	2.9	58	1.2
	2. Conventional, degraded pasture			3.6	72	1.5
	3. Improved pasture			2.9-5.5	58-110	1.2 - **2.3**
	4. Secondary Forest			2.1	42	0.9
	5. Forest in equilibrium			1.8-2.7	36-54	0.7-1.1
	6. Improved cropland [2]			-	-	-
2. Degraded Pasture	1. Improved pasture	35.0	32.3	-1.3-1.9	-26-38	-0.8-**1.2**
	2. Natural regeneration to forest in equilibr.			0.6-1.6	12-32	0.4-1.0
	3. Improved cropland [2]			-	-	-
3. Fallow Land	1. Improved pasture	1.0	0.9	-0.4 – 2.6	52	**0.05**
	2. Secondary Forest			0.24	4.8	0.004
	3. Forest in equilibrium			0.86	17.2	0.016
	4. Improved cropland [2]			-	-	
4. Sec. Forest	1. Forest in equilibrium	4.0	3.8	0.7-1.7	14-34	0.05-**0.13**
5. Degraded, non-productive crops	1. Improved pasture	15.0	13.8	-		-
	2. Nat. regeneration to Secondary Forest			-		-
	3. Nat. regeneration to Forest in equilibrium			-		-
	4. Improved cropland [2]			-		-
Total Potential		**77.4**	**71.4**			**3.7**

---

[1] Sources: Research-generated SCS from the "Carbon Sequestration Project, The Netherlands Cooperation C0-010402" (Amézquita *et al.*, 2003) and expert knowledge.

[2] The authors do not have at present available data on SCS for croplands.

The data in Table 7 presents different scenarios for conversion of degraded areas to C-improved land use systems. Considering the more optimistic land transformation option for each type of degraded area --identified as that with maximum carbon sequestration rate (bold underlined figures in Table 7)-- and using expert knowledge on potential area (million ha) to be transformed into various SCS-improved options, a maximum potential estimate of carbon sequestration over a 20-year period upon conversion of the Tropical Andean Hillsides Ecosystem is calculated as follows.

- Converting 20.6 million ha of severely degraded land of Tropical Andean Hillsides into improved pasture systems has a maximum carbon sequestration potential of $2.3*10^{15}$ g C over a 20-year period.
- Converting 32.3 million ha of conventional, moderately-degraded pasture systems of Tropical Andean Hillsides into improved pasture systems has a maximum carbon sequestration potential of $1.2*10^{15}$ g C over a 20-year period.
- Converting 0.9 million ha of fallow land into improved pasture systems has a maximum carbon sequestration potential of $0.05*10^{15}$ g C over a 20-year period.
- Converting 3.8 million ha of secondary forest into conservation areas without human intervention, to evolve into native forest in equilibrium, has a maximum carbon sequestration potential of $0.13*10^{15}$ g C over a 20-year period.

Based on these figures, a first approximation of the potential for carbon sequestration of the Tropical Andean Hillsides, considering the best C-sequestration option for each type of degraded area over a 20-year period, is estimated as $3.7*10^{15}$ g C.

V. Conclusions

Related to Carbon Sequestration Research on the Tropical Andean Hillsides

1. The information on land use distribution and land use change in the Tropical Andean Hillsides Ecosystem since 1950 is scanty. Available information is given by country, but not by ecosystem across countries. A special effort must be made to acquire this important information which is essential for a more precise estimate of carbon sequestration potential.
2. Specific methodological issues related to the proper estimation of SCS need to be considered for any carbon sequestration research project. In particular: (a) a soil sampling design taking into account all factors affecting SCS needs to be used to obtain minimum-variance estimates. Variability of SCS estimates depends on land use type (*i.e.*, higher on degraded land than on improved grass-alone pasture), site conditions (altitude, climate, topography), soil characteristics, and carbon fraction. (b) For statistical comparisons among land use systems, SCS estimates corrected by bulk density and adjusted to fixed soil mass per sampling point must be used. Estimates thus obtained are more precise than those based on fixed soil depth. (c) SCS estimates for a given land use system need to be interpreted on the basis of the historic land use.

3. The present study did not address carbon sequestration research on coffee and other perennial crops grown in the Tropical Andean Hillsides. However, given their economic importance to Andean countries, carbon sequestration research on these crops must be given a high priority.

Related to Carbon Sequestration Research in Tropical America

1. Tropical pasture, agro-pastoral and agro-silvo-pastoral systems are important socio-economic components in TA across all ecosystems. These are key land use systems for carbon sequestration research. Therefore, special attention and support must be given to carbon sequestration research in tropical pasture systems across all ecosystems, particularly to those adapted to the region and representing viable economic alternative to farmers. These include: improved grass-alone, improved grass-legume, improved grass-legume-trees, improved mixed pasture-crop systems such as agro-pastoral systems combining forage grass, forage legumes, fruit trees, other perennial crops and short-cycle crops.
2. In order to succeed in the organization and implementation of a carbon sequestration research network in TA, both, institutional and technical aspects must be considered. Institutional aspects involve the identification of a scientific leader, network nodes in TA's biomes, and leading scientists for specific knowledge areas. Also of vital importance for success is the identification of donor agencies representatives and policy-makers to collaborate with the network. Technical aspects involve agreement on research objectives and methodology, standards and protocols, sampling methods, laboratory analysis standards and procedures, and methods for calculation of SCS and carbon sequestration rates. These aspects are crucial for a valid comparison of research results.

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Annex 4.1

Statistical Analysis of Second C-Sampling Cycle (March-August 2004)
Andean Hillsides Sub-ecosystem, Colombia

- Descriptive Statistics and SCS estimations ANOVA´s and PC/Clusters Analysis based on fixed soil depth: for 10cm – layers, 0-40, 40-100 and 0-100cm, by site x system (Fig 1-6, tables 1-5)
- SCS estimations, ANOVA´s Principal Component Analysis and Clusters Analysis, based on fixed soil mass estimations. (fig 7-9, tables 6-10)

Table 1: ANOVA BLOQUE 1 - El DOVIO

Fuentes de Variación		CT (t /ha/10cm)	CE (t/ha/10cm)	NT (t/ha/10cm)
	gl	Valor de F	Valor de F	Valor de F
Tratamiento	3	25 ***	5.85 **	25.8 ***
Posición(Tratamiento)	12	2.41 ***	3.98 **	1.36
Repetición (Tratamiento x Posición)	32	5.14 ***	2.02 **	2.64 ***
Profundidad(Tratamiento)	12	118.47 ***	5.62 ***	55.27 ***
Posición x Profundidad(Tratamiento)	36	1.94 **	1.49 *	0.62
Residuo	96			
Total	191			
Media		28.32	8.92	2.14
CV (%)		13.85	38	24.25
R-Cuadrado (%)		0.96	74	92

ANOVA BLOQUE 2 - DAGUA - FELIDIA

Fuentes de Variación		CT (t /ha/10cm)	CE (t/ha/10cm)	NT (t/ha/10cm)
	gl	Valor de F	Valor de F	Valor de F
Tratamiento	3	6.45 **	1.04	2.33 *
Posición(Tratamiento)	11	1.02	1.31	0.52
Repetición (Tratamiento x Posición)	30	3.64 ***	1.79	3.91 ***
Profundidad(Tratamiento)	12	55.64 ***	3.04 **	20.43 ***
Posición x Profundidad(Tratamiento)	33	1.23	1.48 *	1.12
Residuo	90			
Total	179			
Media		21.80	6.0	1.80
CV(%)		22.81	47	34
R-Cuadrado (%)		91	65	83

Fig 5: Mean carbon accumulation (Total C, Oxidisable C and Stable C) at 1m depth, in 4 land use systems in 2 blocks of farms. Andean Hillsides, Colombia.

```
bloque     tratamiento                                      Carbono total (ton/ha/1m)
                                                    N          Mean           Std          CV (%)
                               |
EL DOVIO   Bosque Nativo       |***************     12         290.28         66.87        23.04
           Pastura Mejorada    |**********          12         195.14         44.40        22.75
           Pastura Degradad    |*******             12         148.02         38.54        26.04
           Banco Forr Mixto    |*********           12         176.26         29.42        16.69
                               |
DAGUA      Bosque Nativo       |*********           12         176.81         35.94        20.33
           Pastura Mejorada    |********            12         158.68         24.91        15.70
           Pastura Degradad    |********            12         158.44         34.73        21.92
           Banco Forr Mixto    |******               9         118.35         32.90        27.80
                               |
                               -----+----+----+
                                   100  200  300
```

Total C (ton/ha/1m)

```
bloque     tratamiento                                      Carbono Oxidable (ton/ha/1m)
                                                           N         Mean           Std         CV (%)
                               |
EL DOVIO   Bosque Nativo       |**************************    12        193.56         25.80       13.33
           Pastura Mejorada    |**************                12        103.68         16.79       16.19
           Pastura Degradad    |*************                 12         99.79         28.54       28.60
           Banco Forr Mixto    |*************                 12         99.68         13.36       13.40
                               |
DAGUA      Bosque Nativo       |******************            12        135.89         35.47       26.10
           Pastura Mejorada    |**************                12        103.59         17.80       17.18
           Pastura Degradad    |**************                12        107.12         17.88       16.69
           Banco Forr Mixto    |**********                     9         71.77         24.96       34.77
                               |
                               ----+---+---+---+---+---+--
                                  30  60  90 120 150 180
```

Oxidisable C (ton/ha/1m)

```
bloque     tratamiento                                Carbono Estable (ton/ha/1m)
                                                N           Mean        Std         CV (%)
                               |
EL DOVIO   Bosque Nativo       |*******************     12          96.72       55.22       57.09
           Pastura Mejorada    |******************      12          91.45       31.35       34.28
           Pastura Degradad    |**********              12          48.50       16.38       33.77
           Banco Forr Mixto    |***************         12          76.58       19.41       25.34
                               |
DAGUA      Bosque Nativo       |**********              12          50.75       27.41       54.00
           Pastura Mejorada    |***********             12          56.02       18.59       33.18
           Pastura Degradad    |**********              12          51.79       21.46       41.43
           Banco Forr Mixto    |*********                9          46.57       17.43       37.42
                               |
                               ----+---+---+---+---
                                  20  40  60  80
```

Stable C (ton/ha/1m)

Fig 4: Mean carbon accumulation (Total C, Oxidisable C and Stable C) at 40-100cm depth, in 4 land use systems in 2 blocks of farms. Andean Hillsides, Colombia.

```
bloque     tratamiento                                               Carbono total (ton/ha/40-100 cm)
                                                             N        Mean      Std        CV (%)
                               |
EL DOVIO   Bosque Nativo       |*************************    12         125.40      51.76      41.27
           Pastura Mejorada    |***************              12          74.08      26.39      35.62
           Pastura Degradad    |***********                  12          52.92      11.96      22.60
           Banco Forr Mixto    |************                 12          57.90      11.74      20.27
                               |
DAGUA      Bosque Nativo       |***************              12          75.62      28.64      37.87
           Pastura Mejorada    |*************                12          62.77      11.53      18.36
           Pastura Degradad    |***********                  12          54.36      13.03      23.96
           Banco Forr Mixto    |**********                    9          52.12      17.55      33.68
                               |
                               ----+---+---+---+---+---+-
                                  20  40  60  80  100 120
```

Total C (ton/ha/40-100 cm)

```
bloque     tratamiento                             Carbono Oxidable (ton/ha/40-100 cm)
                                                  N       Mean         Std       CV (%)
                               |
EL DOVIO   Bosque Nativo       |**************   12         67.54         15.50    22.95
           Pastura Mejorada    |******           12         28.09         10.66    37.94
           Pastura Degradad    |******           12         31.24          9.37    29.98
           Banco Forr Mixto    |*****            12         24.14          7.70    31.90
                               |
DAGUA      Bosque Nativo       |************     12         59.16         26.50    44.78
           Pastura Mejorada    |******           12         27.56          9.10    33.01
           Pastura Degradad    |*****            12         26.39          8.75    33.14
           Banco Forr Mixto    |*****             9         24.67         10.78    43.69
                               |
                               ----+---+---+-
                                  20  40  60
```

Oxidisable C (ton/ha/40-100 cm)

```
bloque     tratamiento                                              Carbono Estable (ton/ha/40-100 cm)
                                                           N       Mean      Std       CV (%)
                               |
EL DOVIO   Bosque Nativo       |***********************    12        57.85      48.48    83.79
           Pastura Mejorada    |******************         12        45.99      20.25    44.01
           Pastura Degradad    |*********                  12        21.67       8.89    41.01
           Banco Forr Mixto    |**************             12        33.76      10.32    30.57
                               |
DAGUA      Bosque Nativo       |**********                 12        25.16      22.65    89.98
           Pastura Mejorada    |**************             12        35.20      11.85    33.67
           Pastura Degradad    |***********                12        27.97      13.64    48.74
           Banco Forr Mixto    |***********                 9        27.45      13.55    49.38
                               |
                               ----+---+---+---+---+---
                                  10  20  30  40  50
```

Stable C (ton/ha/40-100 cm)

Fig 3: Mean carbon accumulation (Total C, Oxidisable C and Stable C) at 0-40cm depth, in 4 land use systems in 2 blocks of farms. Andean Hillsides, Colombia.

```
bloque      tratamiento                                                    Carbono Total (ton/ha/0-40 cms)
                                                       N          Mean          Std        CV (%)
                                |
EL DOVIO    Bosque Nativo       |**********************        12         164.88         22.46      13.62
            Pastura Mejorada    |****************              12         121.05         22.94      18.95
            Pastura Degradad    |*************                 12          95.09         28.15      29.60
            Banco Forr Mixto    |****************              12         118.35         19.53      16.50
                                |
DAGUA       Bosque Nativo       |*************                 12         101.18         19.67      19.43
            Pastura Mejorada    |*************                 12          95.91         22.29      23.23
            Pastura Degradad    |**************                12         104.07         23.67      22.75
            Banco Forr Mixto    |*********                      9          66.23         21.11      31.88
                                |
                                ----+---+---+---+---+--
                                   30  60  90 120 150
```

Total C (ton/ha/0-40 cm)

```
bloque      tratamiento                                                Carbono Oxidable (ton/ha/0-40 cm)
                                                          N          Mean          Std          CV (%)
                                |
EL DOVIO    Bosque Nativo       |*************************        12          126.01        16.48        13.08
            Pastura Mejorada    |***************                  12           75.59         8.51        11.25
            Pastura Degradad    |**************                   12           68.54        20.58        30.03
            Banco Forr Mixto    |***************                  12           75.54         9.03        11.95
                                |
DAGUA       Bosque Nativo       |***************                  12           76.72        14.15        18.44
            Pastura Mejorada    |***************                  12           76.02        14.34        18.86
            Pastura Degradad    |****************                 12           80.73        13.66        16.92
            Banco Forr Mixto    |*********                         9           47.10        16.51        35.05
                                |
                                ----+---+---+---+---+---+-
                                   20  40  60  80 100 120
```

Oxidisable C (ton/ha/0-40 cm)

```
bloque      tratamiento                                                    Carbono Estable (ton/ha/0-40 cm)
                                                       N          Mean          Std          CV (%)
                                |
EL DOVIO    Bosque Nativo       |*******************           12          38.87        11.03         28.38
            Pastura Mejorada    |***********************       12          45.45        16.05         35.30
            Pastura Degradad    |*************                 12          26.83        12.36         46.06
            Banco Forr Mixto    |*********************         12          42.81        11.83         27.63
                                |
DAGUA       Bosque Nativo       |*************                 12          25.58         7.65         29.89
            Pastura Mejorada    |**********                    12          20.82        10.39         49.89
            Pastura Degradad    |************                  12          23.82        11.69         49.07
            Banco Forr Mixto    |**********                     9          19.12         6.66         34.83
                                |
                                -----+----+----+----+--
                                    10   20   30   40
```

Stable C (ton/ha/0-40 cm)

Fig 2: Mean carbon accumulation (Total C, Oxidisable C and Stable C) per depth (ton/ha in 10 cm layers) in 4 land use systems in 2 blocks of farms. Andean Hillsides, Colombia.

Block 2 = DAGUA

```
tratamiento        profundidad                                   Carbono Oxidable  (ton/ha/10 cm)
                                                     Freq        Mean        std       cv (%)
                                 |
Bosque Nativo      (0-10)        |**************       12        28.07       9.21      32.82
                   (10-20)       |**********           12        19.41       5.14      26.46
                   (20-40)       |*******              12        14.61       2.04      13.98
                   (40-100)      |*****                12         9.86       4.42      44.78
                                 |
Pastura Mejorada   (0-10)        |****************     12        31.53       8.78      27.85
                   (10-20)       |**********           12        20.53       6.18      30.08
                   (20-40)       |******               12        11.97       3.67      30.67
                   (40-100)      |**                   12         4.59       1.52      33.01
                                 |
Pastura Degradad   (0-10)        |***************      12        30.90       6.93      22.44
                   (10-20)       |************         12        24.72       6.94      28.09
                   (20-40)       |******               12        12.55       1.21       9.65
                   (40-100)      |**                   12         4.39       1.46      33.14
                                 |
Banco Forr Mixto   (0-10)        |*********             9        18.30       7.37      40.26
                   (10-20)       |*******               9        13.58       6.92      50.95
                   (20-40)       |****                  9         7.60       3.71      48.75
                   (40-100)      |**                    9         4.11       1.80      43.69
                                 |
                                 ----+----+----+-
                                    10   20   30
```

Oxidisable C (ton/ha/10cm)

```
tratamiento        profundidad                                   Carbono Estable  (ton/ha/10 cm)
                                                     Freq        Mean        std       cv (%)
                                 |
Bosque Nativo      (0-10)        |*****************    12         8.55       2.48      28.94
                   (10-20)       |************         12         5.82       1.80      30.82
                   (20-40)       |***********          12         5.59       3.37      60.27
                   (40-100)      |********             12         4.19       3.77      89.98
                                 |
Pastura Mejorada   (0-10)        |**************       12         6.81       3.07      45.05
                   (10-20)       |*********            12         4.47       0.79      17.64
                   (20-40)       |**********           12         4.76       3.95      82.83
                   (40-100)      |************         12         5.86       1.98      33.67
                                 |
Pastura Degradad   (0-10)        |****************     12         8.11       5.01      61.71
                   (10-20)       |***********          12         5.64       2.26      40.07
                   (20-40)       |**********           12         5.02       4.78      95.03
                   (40-100)      |*********            12         4.66       2.27      48.74
                                 |
Banco Forr Mixto   (0-10)        |*********             9         4.59       1.78      38.76
                   (10-20)       |***********           9         5.25       0.67      12.73
                   (20-40)       |*********             9         4.63       3.26      70.22
                   (40-100)      |*********             9         4.57       2.26      49.38
                                 |
                                 ----+----+----+----+-
                                     2    4    6    8
```

Stable C (ton/ha/10cm)

Fig 2: Mean carbon accumulation (Total C, Oxidisable C and Stable C) per depth (ton/ha in 10 cm layers) in 4 land use systems in 2 blocks of farms. Andean Hillsides, Colombia.

Block 1 = EL DOVIO

```
tratamiento          profundidad                                           Carbono Estable (ton/ha/10cm)
                                                               Freq          Mean       std     cv (%)
                                   |
Bosque Nativo        (0-10)        |****************            12          7.78      3.59     46.04
                     (10-20)       |******************          12          9.04      1.21     13.41
                     (20-40)       |**********************      12         11.01      4.99     45.32
                     (40-100)      |*******************         12          9.64      8.08     83.79
                                   |
Pastura Mejorada     (0-10)        |********************        12          9.88      0.80      8.12
                     (10-20)       |************************    12         11.93      3.01     25.22
                     (20-40)       |************************    12         11.81      7.13     60.34
                     (40-100)      |***************             12          7.66      3.37     44.01
                                   |
Pastura Degradad     (0-10)        |******************          12          8.83      4.68     53.05
                     (10-20)       |******************          12          9.04      5.14     56.81
                     (20-40)       |*********                   12          4.48      2.66     59.31
                     (40-100)      |*******                     12          3.61      1.48     41.01
                                   |
Banco Forr Mixto     (0-10)        |********************        12          9.81      0.88      8.96
                     (10-20)       |************************    12         11.89      1.07      8.98
                     (20-40)       |*********************       12         10.55      5.56     52.72
                     (40-100)      |***********                 12          5.62      1.72     30.57
                                   |
                                   ----+---+---+---+---+---+
                                       2   4   6   8  10  12
```

Stable C (ton/ha/10 cm)

Block 2 = DAGUA

```
tratamiento          profundidad                                    Carbono Total (ton/ha/10cm)
                                                          Freq         Mean        std     cv (%)
                                   |
Bosque Nativo        (0-10)        |******************     12         36.63      11.31     30.88
                     (10-20)       |*************          12         25.24       6.40     25.33
                     (20-40)       |**********             12         19.65       3.94     20.07
                     (40-100)      |******                 12         12.60       4.77     37.87
                                   |
Pastura Mejorada     (0-10)        |*******************    12         38.34      11.21     29.24
                     (10-20)       |*************          12         25.01       5.91     23.63
                     (20-40)       |********               12         16.27       3.21     19.74
                     (40-100)      |*****                  12         10.46       1.92     18.36
                                   |
Pastura Degradad     (0-10)        |********************   12         39.02       6.12     15.68
                     (10-20)       |***************        12         30.36       8.33     27.44
                     (20-40)       |*********              12         17.34       5.71     32.91
                     (40-100)      |*****                  12          9.06       2.17     23.96
                                   |
Banco Forr Mixto     (0-10)        |***********             9         22.90       6.84     29.88
                     (10-20)       |*********               9         18.83       7.39     39.22
                     (20-40)       |******                  9         12.24       5.88     48.01
                     (40-100)      |****                    9          8.68       2.93     33.68
                                   |
                                   -----+----+----+----+
                                       10   20   30   40
```

Total C (ton/ha/10 cm)

Fig 2: Mean carbon accumulation (Total C, Oxidisable C and Stable C) per depth (ton/ha in 10 cm layers) in 4 land use systems in 2 blocks of farms. Andean Hillsides, Colombia.

Block 1 = EL DOVIO

```
tratamiento         profundidad                                            Carbono Total(ton/ha/10cm)
                                                             Freq         Mean        std      cv (%)
                                  |
Bosque Nativo       (0-10)        |**********************       12         43.92       8.39     19.09
                    (10-20)       |************************     12         47.92       6.31     13.17
                    (20-40)       |******************           12         36.51       6.75     18.48
                    (40-100)      |**********                   12         20.90       8.63     41.27
                                  |
Pastura Mejorada    (0-10)        |********************         12         40.95       4.77     11.64
                    (10-20)       |*****************            12         34.36       6.86     19.95
                    (20-40)       |***********                  12         22.86       6.63     29.00
                    (40-100)      |******                       12         12.34       4.40     35.62
                                  |
Pastura Degradad    (0-10)        |******************           12         35.15       7.84     22.30
                    (10-20)       |***************              12         29.93      10.49     35.05
                    (20-40)       |********                     12         15.00       6.36     42.40
                    (40-100)      |****                         12          8.82       1.99     22.60
                                  |
Banco Forr Mixto    (0-10)        |*******************          12         37.01       5.21     14.07
                    (10-20)       |*****************            12         34.05       4.83     14.18
                    (20-40)       |************                 12         23.64       6.00     25.38
                    (40-100)      |*****                        12          9.65       1.96     20.27
                                  |
                                  -----+----+----+----+-----
                                      10   20   30   40
```

Total C (ton/ha/10 cm)

```
tratamiento         profundidad                                    Carbono Oxidable (ton/ha/10cm)
                                                        Freq        Mean       std      cv (%)
                                  |
Bosque Nativo       (0-10)        |******************         12         36.13      7.30      20.20
                    (10-20)       |*******************        12         38.87      5.93      15.25
                    (20-40)       |*************              12         25.49      3.91      15.34
                    (40-100)      |******                     12         11.25      2.58      22.95
                                  |
Pastura Mejorada    (0-10)        |****************           12         31.07      5.12      16.49
                    (10-20)       |***********                12         22.43      4.86      21.68
                    (20-40)       |******                     12         11.04      1.46      13.22
                    (40-100)      |**                         12          4.68      1.78      37.94
                                  |
Pastura Degradad    (0-10)        |*************              12         26.32      7.59      28.84
                    (10-20)       |**********                 12         20.89      8.02      38.36
                    (20-40)       |*****                      12         10.66      3.86      36.21
                    (40-100)      |***                        12          5.20      1.56      29.98
                                  |
Banco Forr Mixto    (0-10)        |**************             12         27.20      4.83      17.77
                    (10-20)       |***********                12         22.15      4.51      20.33
                    (20-40)       |*******                    12         13.09      0.90       6.84
                    (40-100)      |**                         12          4.02      1.28      31.90
                                  |
                                  -----+----+----+----
                                      10   20   30
```

Oxidisable C (ton/ha/10 cm)

Fig 1: Bulk density per depth in 4 land use systems (Treatments) evaluated in 2 blocks of farms. Andean Hillsides, Colombia.

Bloque = EL DOVIO

```
tratamiento         profundidad                                              Densidad
                                                                   Freq      Mean        std        cv (%)
                                 |
Bosque Nativo       (0-10)       |************                       12      0.61        0.15       24.38
                    (10-20)      |****************                   12      0.82        0.16       19.00
                    (20-40)      |*****************                  12      0.86        0.19       22.41
                    (40-100)     |***************                    12      0.73        0.16       21.55
                                 |
Pastura Mejorada    (0-10)       |*******************                12      0.94        0.05        5.48
                    (10-20)      |**********************             12      1.10        0.15       13.88
                    (20-40)      |**********************             12      1.08        0.23       21.03
                    (40-100)     |********************               12      0.99        0.25       25.50
                                 |
Pastura Degradad    (0-10)       |**************                     12      0.70        0.09       13.03
                    (10-20)      |*****************                  12      0.83        0.13       15.81
                    (20-40)      |***************                    12      0.77        0.19       25.17
                    (40-100)     |****************                   12      0.78        0.16       19.75
                                 |
Banco Forr Mixto    (0-10)       |********************               12      0.98        0.10       10.43
                    (10-20)      |*************************          12      1.23        0.11        8.54
                    (20-40)      |***********************            12      1.14        0.18       15.90
                    (40-100)     |*****************                  12      0.86        0.13       15.12
                                 |
                                 |
                                 ----+---+---+---+---+---+--
                                    0.2 0.4 0.6 0.8  1  1.2
```

Bulk density (gr/cm3)

Bloque = DAGUA

```
tratamiento         profundidad                                           Densidad
                                                                 Freq    Mean           std        cv (%)
                                 |
Bosque Nativo       (0-10)       |***********                      12    0.54           0.06       11.59
                    (10-20)      |****************                 12    0.78           0.12       15.73
                    (20-40)      |********************             12    0.98           0.11       10.86
                    (40-100)     |********************             12    0.99           0.17       17.17
                                 |
Pastura Mejorada    (0-10)       |*****************                12    0.85           0.10       12.02
                    (10-20)      |********************             12    0.99           0.10        9.66
                    (20-40)      |*********************            12    1.07           0.06        5.29
                    (40-100)     |***********************          12    1.16           0.07        6.07
                                 |
Pastura Degradad    (0-10)       |****************                 12    0.78           0.04        5.51
                    (10-20)      |********************             12    0.97           0.07        6.73
                    (20-40)      |**********************           12    1.11           0.08        7.25
                    (40-100)     |*********************            12    1.06           0.12       11.41
                                 |
Banco Forr Mixto    (0-10)       |******************                9    0.88           0.06        6.65
                    (10-20)      |*********************             9    1.06           0.06        5.85
                    (20-40)      |**********************            9    1.10           0.08        7.33
                    (40-100)     |***********************           9    1.14           0.09        7.98
                                 |
                                 |
                                 ----+---+---+---+---+--
                                    0.2 0.4 0.6 0.8  1
```

Bulk density (gr/cm3)

Table 4: Grouping of sampling points according to first 3 Principal Components at 1m depth. Farm blocks 1 and 2,

Andean Hillsides, Colombia. N= 93, Cluster R^2 =83.8 %

Classification Criteria	**CLUSTER NO.**					
	1 **N=18**	**2** **N=15**	**3** **N=14**	**4** **N=22**	**5** **N=19**	**6** **N=5**
Principal Components	**Cluster Means**					
PC1 (Total C, total N, %sand, low %clay, low CEC)	0.67 H	0.96 M	-0.17 M	-0.85 L	-0.85 L	2.21 L
PC2 (Stable C, % clay)	-0.84 H	0.10 M	-1.34 M	0.10 M	1.11 L	1.80 L
Original Soil parameters	***Cluster Means***					
Total C (ton/ha/1m)	167.14	232.43	113.12	159	176.09	357.16
Stable C (ton/ha/1m)	69.72	82.98	41.57	47.34	61.15	159
Total N (ton/ha/1m)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Sand (Th/ha)	4039	3794	3619	2159	1558	4202
Clay (Th/ha)	1930	2032	2593	5108	5916	2224
CEC (Th/ha)	186	186	251	200	163	180
Ph	6.31	6.06	9.91	5.43	5.27	5.90

```
tratamiento        profundidad                                            Arena  (Th/ha)
                                                                N        Mean      Std              CV (%)
                                    |
Bosque Nativo      (0-10)           |*************              4      264.93    57.22              21.60
                   (10-20)          |**********                 4      208.91    68.45              32.76
                   (20-40)          |**********                 4      199.55    45.20              22.65
                   (40-100)         |***********                4      226.37    49.73              21.97
                                    |
Pastura Mejorada   (0-10)           |************               4      243.20    39.90              16.40
                   (10-20)          |**********                 4      198.00    53.11              26.82
                   (20-40)          |*******                    4      138.33    65.75              47.53
                   (40-100)         |******                     4      118.67    15.15              12.77
                                    |
Pastura Degradad   (0-10)           |*************              4      252.16    42.46              16.84
                   (10-20)          |************               4      243.64    25.95              10.65
                   (20-40)          |*********                  4      184.98    82.01              44.33
                   (40-100)         |*******                    4      136.83   100.49              73.44
                                    |
Banco Forr Mixto   (0-10)           |**************             3      278.28    48.62              17.47
                   (10-20)          |****************           3      310.02   120.41              38.84
                   (20-40)          |*****************          3      338.65   119.25              35.21
                   (40-100)         |********************       3      392.84   124.76              31.76
                                    |
                                    +----+----+----+----+
                                        100  200  300  400
```

Sand (ton/ha)

```
tratamiento        profundidad                                         CIC  (Th/ha)
                                                             N       Mean          Std              CV (%)
                                    |
Bosque Nativo      (0-10)           |********                4       15.58         0.73              4.69
                   (10-20)          |*********               4       17.27         0.54              3.13
                   (20-40)          |**********              4       19.39         2.41             12.41
                   (40-100)         |**********              4       20.84         2.99             14.34
                                    |
Pastura Mejorada   (0-10)           |***********             4       21.63         1.96              9.08
                   (10-20)          |***********             4       21.69         2.62             12.09
                   (20-40)          |**********              4       19.71         5.11             25.94
                   (40-100)         |**********              4       19.62         6.95             35.42
                                    |
Pastura Degradad   (0-10)           |*********               4       17.97         1.68              9.37
                   (10-20)          |*********               4       18.26         0.20              1.12
                   (20-40)          |*******                 4       13.92         2.86             20.54
                   (40-100)         |******                  4       11.83         1.19             10.02
                                    |
Banco Forr Mixto   (0-10)           |**************          3       28.78         1.64              5.70
                   (10-20)          |*****************       3       33.76         3.59             10.63
                   (20-40)          |****************        3       31.62         1.74              5.51
                   (40-100)         |****************        3       31.88         7.18             22.53
                                    |
                                    +----+----+----+--
                                        10   20   30
```

CEC (ton/ha)

Block 2 = DAGUA

```
tratamiento         profundidad                                Nitrógeno Total (ton/ha/10cm)
                                                           Freq         Mean         std       cv (%)
                                  |
Bosque Nativo       (0-10)        |**********               12         2.01         1.02      50.40
                    (10-20)       |**********               12         1.93         0.93      48.10
                    (20-40)       |******                   12         1.13         0.63      55.96
                    (40-100)      |*****                    12         1.06         1.56     146.69
                                  |
Pastura Mejorada    (0-10)        |****************         12         3.28         1.08      32.79
                    (10-20)       |************             12         2.40         0.76      31.57
                    (20-40)       |********                 12         1.59         0.66      41.61
                    (40-100)      |*****                    12         0.99         0.34      33.86
                                  |
Pastura Degradad    (0-10)        |***************          12         3.05         0.52      17.04
                    (10-20)       |*************            12         2.50         0.58      23.15
                    (20-40)       |********                 12         1.53         0.48      31.16
                    (40-100)      |****                     12         0.80         0.18      22.06
                                  |
Banco Forr Mixto    (0-10)        |***********               9         2.29         0.68      29.86
                    (10-20)       |*********                 9         1.84         0.73      39.52
                    (20-40)       |******                    9         1.23         0.66      53.34
                    (40-100)      |*****                     9         0.92         0.36      38.79
                                  |
                                  -----+----+----+-
                                       1    2    3
```

Total N (ton/ha/10 cm)

```
tratamiento         profundidad                                              Arcilla (Th/ha)
                                                        Freq          Mean        std      cv (%)
                                  |
Bosque Nativo       (0-10)        |****                  4          216.33      50.04     23.13
                    (10-20)       |********              4          391.63      31.33      8.00
                    (20-40)       |**********            4          524.73      14.78      2.82
                    (40-100)      |**********            4          489.00      51.67     10.57
                                  |
Pastura Mejorada    (0-10)        |********              4          394.32      31.90      8.09
                    (10-20)       |**********            4          506.95      39.97      7.88
                    (20-40)       |************          4          609.16      73.81     12.12
                    (40-100)      |**************        4          695.91      15.53      2.23
                                  |
Pastura Degradad    (0-10)        |*******               4          337.00      58.68     17.41
                    (10-20)       |*********             4          473.04      68.36     14.45
                    (20-40)       |*************         4          632.17      42.37      6.70
                    (40-100)      |************          4          623.86     114.13     18.29
                                  |
Banco Forr Mixto    (0-10)        |******                3          307.39      68.98     22.44
                    (10-20)       |********              3          399.07     102.96     25.80
                    (20-40)       |********              3          408.28     116.44     28.52
                    (40-100)      |********              3          384.37     105.12     27.35
                                  |
                                  ----+---+---+--
                                     200 400 600
```

Clay (ton/ha)

```
tratamiento        profundidad                                   Arena (Th/Ha)
                                                         N       Mean       Std           CV(%)
                                  |
Bosque Nativo      (0-10)         |***************       4       303.25     53.69         17.71
                   (10-20)        |*******************   4       387.08     75.95         19.62
                   (20-40)        |********************* 4       412.41     88.77         21.52
                   (40-100)       |*****************     4       347.28     63.97         18.42
                                  |
Pastura Mejorada   (0-10)         |********************* 4       422.35     39.88          9.44
                   (10-20)        |*******************************  4       453.49     35.61          7.85
                   (20-40)        |*******************************  4       455.00     72.74         15.99
                   (40-100)       |**********************  4       438.84     83.08         18.93
                                  |
Pastura Degradad   (0-10)         |*****************     4       346.99     28.23          8.13
                   (10-20)        |********************  4       391.66     30.84          7.87
                   (20-40)        |***************       4       309.46     49.04         15.85
                   (40-100)       |***************       4       306.34     64.71         21.12
                                  |
Banco Forr Mixto   (0-10)         |*******************   4       373.58     60.82         16.28
                   (10-20)        |**********************  4       434.19     75.82         17.46
                   (20-40)        |********************* 4       424.94     88.12         20.74
                   (40-100)       |*******************   4       377.88     57.05         15.10
                                  |
                                  +----+----+----+----+---
                                      100  200  300  400
```

Sand (ton/ha)

```
tratamiento        profundidad                          CIC (Th/Ha)
                                                N       Mean       Std           CV(%)
                                  |
Bosque Nativo      (0-10)         |**********   4       19.94      3.19          15.98
                   (10-20)        |************ 4       24.34      3.44          14.14
                   (20-40)        |***********  4       21.61      1.95           9.02
                   (40-100)       |********     4       16.67      1.81          10.85
                                  |
Pastura Mejorada   (0-10)         |*********    4       17.99      4.63          25.75
                   (10-20)        |*********    4       18.99      4.03          21.21
                   (20-40)        |*********    4       18.94      1.85           9.75
                   (40-100)       |*********    4       17.87      1.12           6.27
                                  |
Pastura Degradad   (0-10)         |***********  4       22.50      1.71           7.60
                   (10-20)        |************ 4       24.14      3.44          14.26
                   (20-40)        |*********    4       18.56      2.19          11.79
                   (40-100)       |********     4       16.03      1.21           7.52
                                  |
Banco Forr Mixto   (0-10)         |**********   4       19.06      1.11           5.84
                   (10-20)        |**********   4       20.69      1.11           5.37
                   (20-40)        |**********   4       20.11      1.85           9.20
                   (40-100)       |*********    4       17.85      1.38           7.74
                                  |
                                  +----+----+--
                                      10   20
```

CEC (ton/ha)

Fig 6: Soil parameters that show association with Total C or with Stable C (evaluated at 4 soil depths in 10cm layers, in 4 land use systems in 2 blocks of farms):

Total N, Sand, Clay and CEC (ton/ha/per 10cm soil layers)

Block 1 = EL DOVIO

```
tratamiento       profundidad                                          Nitrógeno Total (ton/ha/10cm)
                                                         Freq          Mean        std       cv (%)
                                 |
Bosque Nativo     (0-10)         |*******************       12          3.76        0.94      24.91
                  (10-20)        |*******************       12          3.82        0.46      11.94
                  (20-40)        |***************           12          3.05        0.65      21.35
                  (40-100)       |********                  12          1.51        0.82      54.43
                                 |
Pastura Mejorada  (0-10)         |****************          12          3.13        0.51      16.41
                  (10-20)        |***********               12          2.29        0.49      21.47
                  (20-40)        |******                    12          1.25        0.39      31.17
                  (40-100)       |***                       12          0.60        0.27      44.49
                                 |
Pastura Degradad  (0-10)         |**************            12          2.83        0.63      22.07
                  (10-20)        |***********               12          2.28        0.93      40.63
                  (20-40)        |*****                     12          1.03        0.45      43.82
                  (40-100)       |**                        12          0.44        0.20      44.51
                                 |
Banco Forr Mixto  (0-10)         |*****************         12          3.35        0.92      27.51
                  (10-20)        |*************             12          2.63        0.68      26.00
                  (20-40)        |********                  12          1.68        0.53      31.52
                  (40-100)       |***                       12          0.64        0.17      27.11
                                 |
                                 -----+----+----+---
                                      1    2    3
```

Total N (ton/ha/10 cm)

```
tratamiento       profundidad                                      Arcilla (Th/ha)
                                                      Freq         Mean       std       cv (%)
                                 |
Bosque Nativo     (0-10)         |********                4        167.36      46.70    27.90
                  (10-20)        |***********             4        229.87      50.61    22.02
                  (20-40)        |***********             4        216.79      72.08    33.25
                  (40-100)       |********                4        150.67      34.60    22.96
                                 |
Pastura Mejorada  (0-10)         |***********             4        212.75      27.68    13.01
                  (10-20)        |**************          4        281.38      75.25    26.74
                  (20-40)        |*************           4        260.53     105.66    40.55
                  (40-100)       |***********             4        213.09     120.42    56.51
                                 |
Pastura Degradad  (0-10)         |********                4        161.62      48.78    30.18
                  (10-20)        |*********               4        189.32      85.00    44.90
                  (20-40)        |***********             4        228.77     225.47    98.55
                  (40-100)       |************            4        247.14     186.83    75.60
                                 |
Banco Forr Mixto  (0-10)         |************            4        243.49      12.37     5.08
                  (10-20)        |*****************       4        343.00      22.19     6.47
                  (20-40)        |***************         4        305.10      53.70    17.60
                  (40-100)       |*********               4        171.64      40.99    23.88
                                 |
                                 -----+----+----+--
                                     100  200  300
```

Clay (ton/ha)

Table 3c: Association between Soil and Carbon variables at 40-100cm: Principal Component Analysis.
Variance explained: 69.28 %

Variable	PC_1 (38.37%)	PC_2 (30.91%)
Total C (ton/ha/40-100cm)	0.38	0.47*
Total N (ton/ha/40-100cm)	0.20	0.49*
Stable C (ton/ha/40-100cm)	0.39	0.42*
Sand (ton/ha/40-100cm)	0.49*	-0.30
Clay (ton/ha/40-100 cm)	-0.46*	0.32
pH (mean in 4-100 cm)	0.42*	-0.34
CEC (ton/ha/40-100cm)	0.069	-0.17

PC1: Soil texture (predominance of sand over clay) and lower acidity
PC2: Total and Stable C and total N

Table 3b: Association between Soil and Carbon variables at 1m: Principal Component Analysis.

Variance explained 71.85 %

Variable	PC_1 (42.86%)	PC_2 (29%)
Total C (ton/ha/1m)	0.39	0.45*
Total N (ton/ha/1m)	0.27	0.48*
Stable C (ton/ha/1m)	0.43*	0.32
Sand (ton/ha/1m)	0.46*	-0.34
Clay (ton/ha/1m)	-0.43*	0.32
pH (mean in 1m)	0.41*	-0.35
CEC (ton/ha/1m)	0.024	-0.32

PC1: Stable C with predominance of sand over clay
PC2: Total C and total N

Table 3a: Association between Soil and Carbon variables at 0-40cm: Principal Component Analysis. Variance explained: 73.19 %

Variable	PC_1 (46.07%)	PC_2 (27.12%)
Total C (ton/ha/0-40cm)	0.40	0.46*
Total N (ton/ha/0-40cm)	0.33	0.41*
Stable C (ton/ha/0-40cm)	0.44*	0.25
Sand (ton/ha/0-40cm)	0.45*	-0.29
Clay (ton/ha/0-40 cm)	-0.37	0.35
pH (ton/ha/0-40 cm)	0.41	-0.38
CEC (ton/ha/0-40cm)	0.023	-0.43

PC1: Stable C and total N with predominance of sand over clay
PC2: Total C and total N

Table 2 (cont): C Storage by System, at 1m, 0-40, 40-100cm.

BLOCK 2 (1350m.a.s.l.), Andean Hillsides, Colombia.

Depth (cm)	**SYSYEM**	**Mean Total C** (ton/ha)		**Mean Stable C** (ton/ha)	
0-100 cm	**Native Forest**	176.81	A	50.75	A
	Improved pasture	158.69	A	56.02	A
	Degraded pasture	158.44	A	51.79	A
	Forage Bank	118.35	B	46.57	A
Mean, CV(%) and LSD .10		**155.4, 20% , 27.04**		**51.6, 39%, 17.4**	
0-40 cm	Native Forest	101.18	A	25.58	A
	Improved pasture	95.91	A	20.82	A
	Degraded pasture	104.07	A	23.82	A
	Forage Bank	66.23	B	19.12	A
Mean, CV(%) and LSD .10		**94, 23%, 18.70**		**22.55, 39%, 13.8**	
40-100 cm	Native Forest	75.62	A	25.16	A
	Improved pasture	62.77	AB	35.20	A
	Degraded pasture	54.36	B	27.97	A
	Forage Bank	52.12	B	27.45	A
Mean, CV(%) and LSD .10		**62, 30%, 16.58**		**29.04, 52%, 12.98**	

Table 2: C Storage by System, at 1m, 0-40cm and 40-100cm.
BLOCK 1 (1750 m.a.s.l.), Andean Hillsides, Colombia.

Depth (cm)	System	Mean Total C (ton/ha)		Mean Stable C (ton/ha)	
0-100 cm	**Native Forest**	290.29	A	96.73	A
	Improved pasture	195.14	B	91.45	A
	Degraded pasture	148.02	C	48.51	B
	Forage Bank	176.27	BC	76.58	A
	Mean, CV (%) and LSD $_{.10}$	**202.46, 20%, 33.69**		**78.3, 43%, 28**	
0-40 cm	**Native Forest**	164.8	A	38.8	A
	Improved pasture	121.0	B	45.4	A
	Degraded pasture	95.01	C	26.8	B
	Forage Bank	118.3	B	42.8	A
	Mean, CV (%) and LSD $_{.10}$	**124.8, 15%, 15.63**		**34.3, 56%, 15.8**	
40-100 cm	**Native Forest**	125.4	A	57.85	A
	Improved pasture	74.09	B	46	AB
	Degraded pasture	52.92	B	21.68	C
	Forage Bank	57.91	B	33.77	BC
	Mean, CV (%) and LSD $_{.10}$	**77.6, 35.5% , 22.9**		**39.8, 69%, 22.9**	

Fuentes de Variación		CT (t/ha/1m)	CE (t/ha/1m)	NT (t/ha/1m)
	gl	Valor de F	Valor de F	Valor de F
Tratamiento	3	27.82 * **	4.95 **	31.92 ***
Posición(Tratamiento)	12	2.24 **	1.12	1.26
Residuo = Repetición (Tratamiento x Posición)	32			
Total	47			
Media		202.43	78.3	14.36
CV (%)		20	43	25
R-Cuadrado (%)		77.5	47	77.6

BLOQUE 2 - DAGUA - FELIDIA

Fuentes de Variación		CT (t/ha/1m)	CE (t/ha/1m)	NT (t/ha/1m)
	gl	Valor de F	Valor de F	Valor de F
Tratamiento	3	6.21 **	0.39	0.36
Posición(Tratamiento)	11	1.29	1.67	0.63
Residuo	30			
Total	44			
Media		155.38	51.6	13.33
CV (%)		20.05	39	50.36
R-Cuadrado (%)		52	39.5	21

ANOVA (cont.) BLOQUE 1 - El DOVIO

Fuentes de Variación		CT (t/ha/0-40cm)	CE (t/ha/0-40cm)	NT (t/ha/0-40cm)	CT (t/ha/40-100cm)	CE (t/ha/40-100cm)	NT (t/ha/40-100cm)
	gl	Valor de F	Valor de F	Valor de F	Valor de F	Valor de F	Valor de F
Tratamiento	3	28.80 ***	6.98 ***	26.52 ***	17.37 ***	3.85 *	11.87 ***
Posición(Tratamiento)	12	3.05 **	2.62 *	1.32	1.75 *	0.89	0.54 **
Residuo = Repetición (Tratamiento x Posición)	32						
Total	47						
Media		124.84	38.49	9.54	77.6	39.82	4.81
CV (%)		15	28.04	20.5	35.5	69.15	60.4
R-Cuadrado (%)		79	62	75	69.5	41	58

ANOVA (cont.) BLOQUE 2 - DAGUA - FELIDIA

Fuentes de Variación		CT (t/ha/0-40cm)	CE (t/ha/0-40cm)	NT (t/ha/0-40cm)	CT (t/ha/40-100cm)	CE (t/ha/40-100cm)	NT (t/ha/40-100cm)
	gl	Valor de F	Valor de F	Valor de F	Valor de F	Valor de F	Valor de F
Tratamiento	3	6.33 ***	1.14	3.76 **	3.48 **	1	0.19
Posición(Tratamiento)	11	1.08	1.48	0.73	0.96	1.62	0.70
Residuo = Repetición (Tratamiento x Posición)	30						
Total	44						
Media		94	22.55	7.65	61.82	29.04	5.68
CV (%)		23	39.57	31	30.9	52	93.1
R-Cuadrado (%)		51	40	39	41	41	21.5

Table 8a: Association between Soil and Carbon variables at 0-40cm-equiv: Principal Component Analysis.

Variance explained: 74 %

Variable	PC_1 (41%)	PC_2 (33%)
Total C (ton/ha/0-40cm-equiv)	0.20	0.58*
Total N (ton/ha/0-40cm-equiv)	0.20	0.54*
Stable C (ton/ha/0-40cm-equiv)	0.34	0.41*
Sand (ton/ha/0-40cm-equiv)	-0.53*	-0.24
Clay (ton/ha/0-40 cm-equiv)	0.51*	0.17
pH (mean in 0-40 cm-equiv)	0.47*	-0.38
CEC (ton/ha/0-40cm-equiv)	-0.14	0.091

PC1:	Soil texture and acidity
PC2:	Total and Stable C, with total N

Table 7 (cont): C Storage by System, at 1m-equiv, 0-40-equiv, 40-100cm-equiv. BLOCK 2 (1350m.a.s.l.), Andean Hillsides, Colombia.

Depth (cm)	SYSYEM	Mean Total C (ton/ha)		Mean Stable C (ton/ha)	
0-100 cm	**Native Forest**	176.81	A	50.75	A
	Improved pasture	158.69	A	56.02	A
	Degraded pasture	158.44	A	51.79	A
	Forage Bank	118.35	B	46.57	A
	Mean, CV(%) and LSD .10	**136.78, 20% , 24.99**		**51.6, 39%, 17.4**	
0-40 cm	Native Forest	95.77	A	23.71	A
	Improved pasture	81.34	A	16.32	A
	Degraded pasture	89.06	A	19.45	AB
	Forage Bank	53.58	B	14.37	B
	Mean, CV(%) and LSD .10	**81.69, 24%, 16.84**		**18.73, 35%, 5.75**	
40-100 cm	Native Forest	24.61	A	7.14	A
	Improved pasture	15.50	B	8.87	A
	Degraded pasture	9.07	C	5.08	A
	Forage Bank	12.35	BC	6.57	A
	Mean, CV(%) and LSD .10	**16, 31%, 4.20**		**6.94, 69%, 4.19**	

Table 7: C Storage by System, at 1m-equiv, 0-40cm-equiv and 40-100cm-equiv

BLOCK 1 (1750 m.a.s.l.), Andean Hillsides, Colombia.

Depth (cm)	System	Mean Total C (ton/ha)		Mean Stable C (ton/ha)	
0-100 cm	**Native Forest**	164.24	**A**	45.09	**A**
	Improved pasture	141.03	**AB**	42.29	**A**
	Degraded pasture	134.61	**B**	42.56	**A**
	Forage Bank	97.40	**C**	35.51	**A**
	Mean, CV (%) and LSD .10	**162.43, 21%, 22.73**		**41.7, 39%, 14.3**	
0-40 cm	**Native Forest**	139.2	**A**	31.63	**A**
	Improved pasture	83.93	**B**	25.73	**B**
	Degraded pasture	82.14	**B**	22.87	**B**
	Forage Bank	76.41	**B**	23.98	**B**
	Mean, CV (%) and LSD .10	**95.42, 15%, 12.2**		**18.73, 35%, 5.56**	
40-100 cm	**Native Forest**	50.32	**A**	22.09	**A**
	Improved pasture	30.83	**B**	18.83	**A**
	Degraded pasture	13.49	**C**	4.99	**B**
	Forage Bank	18.72	**C**	10.53	**B**
	Mean, CV (%) and LSD .10	**28.34, 33.6% , 7.92**		**14, 68%, 7.92**	

ANOVA: BLOQUE 1 - El DOVIO

Fuentes de Variación		CT (t/ha/1m)	CE (t/ha/1m)	NT (t/ha/1m)
	gl	Valor de F	Valor de F	Valor de F
Tratamiento	3	48.86 ***	6.16 ***	47.23 ***
Posición(Tratamiento)	12	1.68	1.32	0.86
Residuo = Repetición (Tratamiento x Posición)	32			
Total	47			
Media		162.43	56.9	11.9
CV (%)		16.8	33.9	21.2
R-Cuadrado (%)		83	51	82

BLOQUE 2 - DAGUA - FELIDIA

Fuentes de Variación		CT (t/ha/1m)	CE (t/ha/1m)	NT (t/ha/1m)
	gl	Valor de F	Valor de F	Valor de F
Tratamiento	3	9.36 ***	0.61	0.44
Posición(Tratamiento)	11	1.29	1.4	0.49
Residuo	30			
Total	44			
Media		136.78	41.7	11.50
CV (%)		21	39.4	47
R-Cuadrado (%)		58	36	18

Table 6: ANOVA's for System's Comparisons in their SCS (based on fixed soil mass estimations)

BLOQUE 1 - El DOVIO

Fuentes de Variación		CT (t/ha/0-40cm) equiv.	CE (t/ha/0-40cm) equiv.	NT (t/ha/0-40cm) equiv.	CT (t/ha/40-100cm) equiv.	CE (t/ha/40-100cm) equiv.	NT (t/ha/40-100cm) equiv.
	gl	Valor de F	Valor de F	Valor de F	Valor de F	Valor de F	Valor de F
Tratamiento	3	48.03 ***	4.07 **	37.14 ***	35.31 ***	7.96 ***	26.82 ***
Posición(Tratamiento)	12	2.11 **	2.68 **	1.03	12.81 ***	2.29 **	6.13 ***
Residuo = Repetición (Tratamiento x Posición)	32						
Total	47						
Media		95.42	26.05	7.53	28.34	14.09	1.74
CV (%)		15	25.69	20.5	33.6	67.62	47.85
R-Cuadrado (%)		84	58	79	89	61	82

BLOQUE 2 - DAGUA – FELIDIA

Fuentes de Variación		CT (t/ha/0-40cm) equiv.	CE (t/ha/0-40cm) equiv.	NT (t/ha/0-40cm) equiv.	CT (t/ha/40-100cm) equiv.	CE (t/ha/40-100cm) equiv.	NT (t/ha/40-100cm) equiv.
	gl	Valor de F	Valor de F	Valor de F	Valor de F	Valor de F	Valor de F
Tratamiento	3	8.97 ***	4.13 **	2.68 *	22.49 ***	1.25	0.85
Posición(Tratamiento)	11	0.88	0.95	0.47	26.13 ***	1.86 *	1.12
Residuo = Repetición (Tratamiento x Posición)	30						
Total	44						
Media		81.69	18.73	6.57	15.58	6.94	1.35
CV (%)		23.75	35.37	31.97	31.04	69.68	110
R-Cuadrado (%)		54	43	30	92	44	33

Fig 9: Mean carbon accumulation (Total C, Oxidisable C and Stable C) at 1m – equiv. depth, in 4 land use systems in 2 blocks of farms. Andean Hillsides, Colombia.

```
bloque      tratamiento                                                       Carbono total (ton/ha/1m-equiv)

                                                                N        Mean        Std           CV (%)
                                  |
EL DOVIO    Bosque Nativo         |************************     12      244.66      44.55          18.21
            Pastura Mejorada      |**************               12      142.45      19.23          13.50
            Pastura Degradad      |*************                12      127.76      27.72          21.70
            Banco Forr Mixto      |*************                12      134.84      20.56          15.24
                                  |
DAGUA       Bosque Nativo         |****************             12      164.24      33.80          20.58
            Pastura Mejorada      |*************                12      134.61      23.06          17.13
            Pastura Degradad      |**************               12      141.03      33.52          23.77
            Banco Forr Mixto      |**********                    9       97.40      26.97          27.69
                                  |
                                  ----+----+----+----+--
                                     50  100  150  200
```

Total C (ton/ha/1m – equiv)

```
bloque      tratamiento                                                       Carbono Oxidable (ton/ha/1m-equiv)

                                                                N        Mean        Std           CV (%)
                                  |
EL DOVIO    Bosque Nativo         |***********************      12      170.21      19.84          11.66
            Pastura Mejorada      |***********                  12       83.22       7.61           9.14
            Pastura Degradad      |************                 12       86.91      19.42          22.34
            Banco Forr Mixto      |***********                  12       81.82       9.08          11.10
                                  |
DAGUA       Bosque Nativo         |*****************            12      128.70      38.01          29.54
            Pastura Mejorada      |************                 12       93.25      16.44          17.63
            Pastura Degradad      |*************                12       98.94      17.44          17.62
            Banco Forr Mixto      |********                      9       61.89      21.12          34.13
                                  |
                                  ---+---+---+---+---+--
                                    30  60  90 120 150
```

Oxidisable C (ton/ha/1m – equiv)

```
bloque      tratamiento                                                       Carbono Estable (ton/ha/1m-equiv)

                                                         N        Mean        Std           CV (%)
                                  |
EL DOVIO    Bosque Nativo         |***************       12       74.45      32.58          43.76
            Pastura Mejorada      |************          12       59.23      14.20          23.97
            Pastura Degradad      |********              12       41.11      14.11          34.30
            Banco Forr Mixto      |***********           12       53.02      13.06          24.64
                                  |
DAGUA       Bosque Nativo         |*********             12       45.09      21.55          47.78
            Pastura Mejorada      |********              12       42.29      14.14          33.42
            Pastura Degradad      |*********             12       42.56      18.77          44.10
            Banco Forr Mixto      |*******                9       35.50      12.04          33.90
                                  |
                                  ----+---+---+----
                                     20  40  60
```

Stable C (ton/ha/1m – equiv)

Fig 8: Mean carbon accumulation (Total C, Oxidisable C and Stable C) at 40-100cm – equiv. depth, in 4 land use systems in 2 blocks of farms. Andean Hillsides, Colombia.

```
bloque     tratamiento                                         Carbono total (ton/ha/40-100 cm-equiv)

                                                          N        Mean       Std            CV (%)
                       |
EL DOVIO   Bosque Nativo   |*************************     12       50.32     30.67           60.96
           Pastura Mejorada|***************               12       30.83     21.21           68.80
           Pastura Degradad|*******                       12       13.49      8.81           65.25
           Banco Forr Mixto|*********                     12       18.72      8.12           43.36

DAGUA      Bosque Nativo   |************                  12       24.61     25.01          101.64
           Pastura Mejorada|********                      12       15.50      3.24           20.92
           Pastura Degradad|*****                         12        9.07      4.47           49.23
           Banco Forr Mixto|******                         9       12.35      5.21           42.20
                           |
                           +----+----+----+----+----+
                               10   20   30   40   50
```

Total C (ton/ha/40-100 cm – equiv)

```
bloque     tratamiento                                    Carbono Oxidable (ton/ha/40-100 cm-equiv)

                                                 N         Mean        Std           CV (%)
                           |
EL DOVIO   Bosque Nativo   |**************       12        28.30       18.76          66.27
           Pastura Mejorada|******               12        11.99        8.93          74.44
           Pastura Degradad|****                 12         8.49        6.84          80.51
           Banco Forr Mixto|****                 12         8.19        4.52          55.17

DAGUA      Bosque Nativo   |*********            12        17.55       20.22         115.23
           Pastura Mejorada|***                  12         6.62        1.73          26.05
           Pastura Degradad|**                   12         3.98        1.60          40.23
           Banco Forr Mixto|***                   9         5.78        2.93          50.72
                           |
                           +----+----+---
                               10   20
```

Oxidisable C (ton/ha/40-100 cm – equiv)

```
bloque     tratamiento                                          Carbono Estable (ton/ha/40-100 cm-equiv)

                                                         N        Mean       Std           CV (%)
                           |
EL DOVIO   Bosque Nativo   |**********************       12       22.01     16.46           74.75
           Pastura Mejorada|*******************          12       18.83     13.84           73.47
           Pastura Degradad|*****                        12        4.99      2.95           59.02
           Banco Forr Mixto|***********                  12       10.53      4.51           42.82

DAGUA      Bosque Nativo   |*******                      12        7.14      8.33          116.58
           Pastura Mejorada|*********                    12        8.87      3.44           38.74
           Pastura Degradad|*****                        12        5.08      3.91           76.85
           Banco Forr Mixto|*******                       9        6.57      3.85           58.52
                           |
                           +----+----+----+----+--
                                5   10   15   20
```

Stable C (ton/ha/40-100 cm – equiv)

SCS Based on fixed Soil Mass Estimations

Fig 7: Mean carbon accumulation (Total C, Oxidisable C and Stable C) at 0-40cm – equiv. depth, in 4 land use systems in 2 blocks of farms. Andean Hillsides, Colombia.

```
bloque    tratamiento                                    Carbono Total (ton/ha/0-40 cms-equiv)

                                            N        Mean        Std          CV (%)

EL DOVIO  Bosque Nativo     |*******************   12      139.20       23.75          17.06
          Pastura Mejorada  |***********           12       83.93        9.55          11.38
          Pastura Degradad  |***********           12       82.14       18.97          23.10
          Banco Forr Mixto  |**********            12       76.41       10.32          13.51

DAGUA     Bosque Nativo     |*************         12       95.77       20.16          21.04
          Pastura Mejorada  |***********           12       81.34       19.61          24.10
          Pastura Degradad  |************          12       89.06       19.24          21.61
          Banco Forr Mixto  |*******                9       53.58       16.51          30.82
                            |
                            +---+---+---+---+--
                               30  60  90 120
```

Total C (ton/ha/0-40 cm – equiv)

```
bloque    tratamiento                                        Carbono Oxidable (ton/ha/0-40 cm-equiv)

                                                N        Mean        Std        CV (%)

EL DOVIO  Bosque Nativo     |**********************   12      107.56       14.77       13.74
          Pastura Mejorada  |************             12       58.20        8.29       14.24
          Pastura Degradad  |************             12       59.50       14.28       24.00
          Banco Forr Mixto  |**********               12       52.42       8.56        16.32

DAGUA     Bosque Nativo     |***************          12       73.12       15.43       21.11
          Pastura Mejorada  |*************            12       65.57       14.01       21.36
          Pastura Degradad  |**************           12       69.89       13.35       19.11
          Banco Forr Mixto  |********                  9       39.21       14.42       36.77
                            |
                            +---+---+---+---+---+--
                               20  40  60  80 100
```

Oxidisable C (ton/ha/0-40 cm – equiv)

```
bloque    tratamiento                                    Carbono Estable (ton/ha/0-40 cm-equiv)

                                         N        Mean       Std            CV (%)

EL DOVIO  Bosque Nativo     |****************   12       31.63      11.31           35.75
          Pastura Mejorada  |*************      12       25.73       3.69           14.33
          Pastura Degradad  |***********        12       22.87      10.60           46.33
          Banco Forr Mixto  |************       12       23.98       2.75           11.48

DAGUA     Bosque Nativo     |************       12       23.71       6.49           27.35
          Pastura Mejorada  |********           12       16.32       6.58           40.30
          Pastura Degradad  |**********         12       19.45       8.23           42.30
          Banco Forr Mixto  |*******             9       14.37       3.40           23.66
                            |
                            +----+----+----+
                                10   20   30
```

Stable C (ton/ha/0-40 cm – equiv)

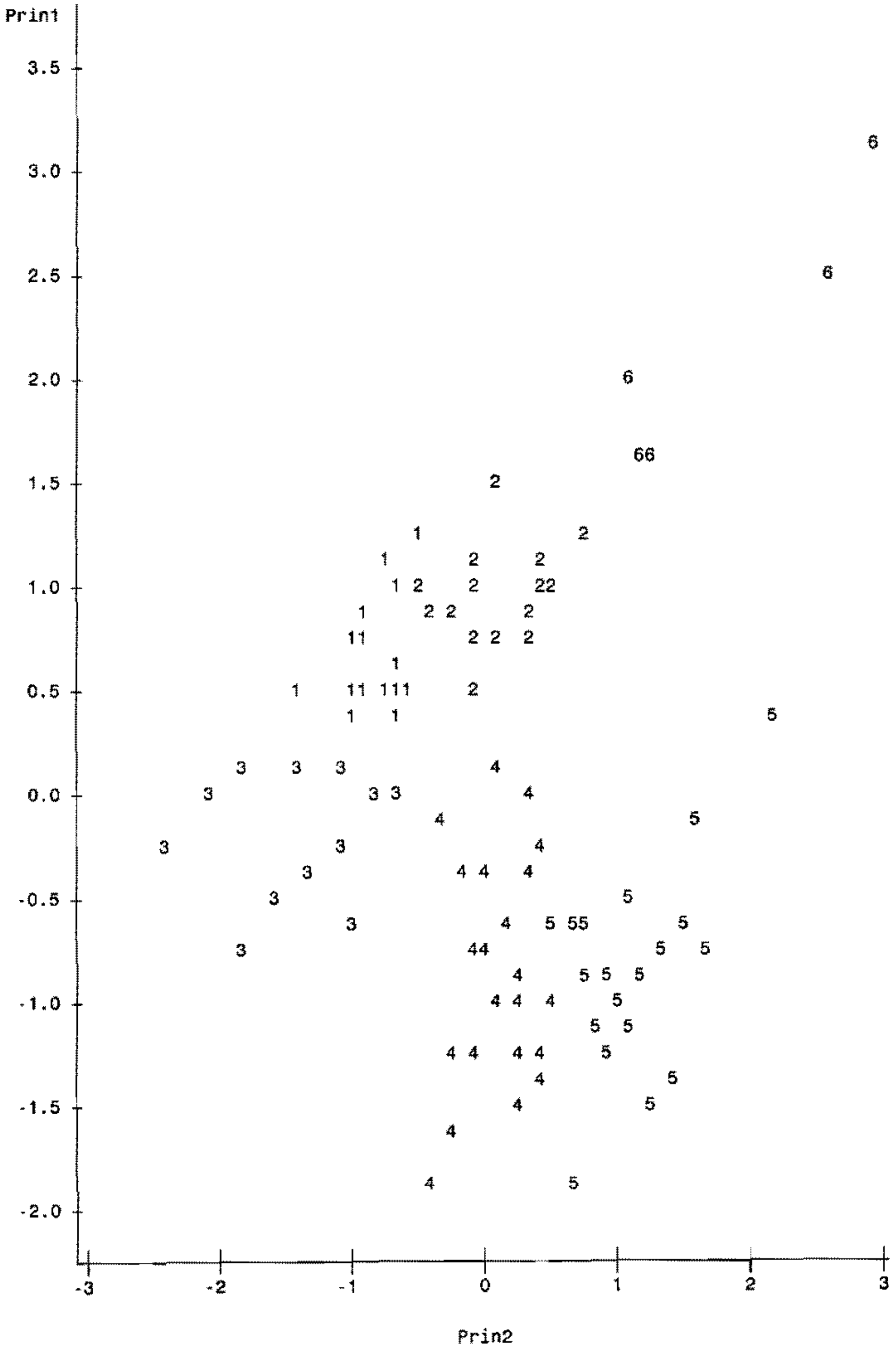
Table 5: C-level per Cluster and Cluster members.

Farm blocks 1 and 2, Andean Hillsides, Colombia.

N=93 sampling points; No. Clusters = 6; R^2=83.8 %

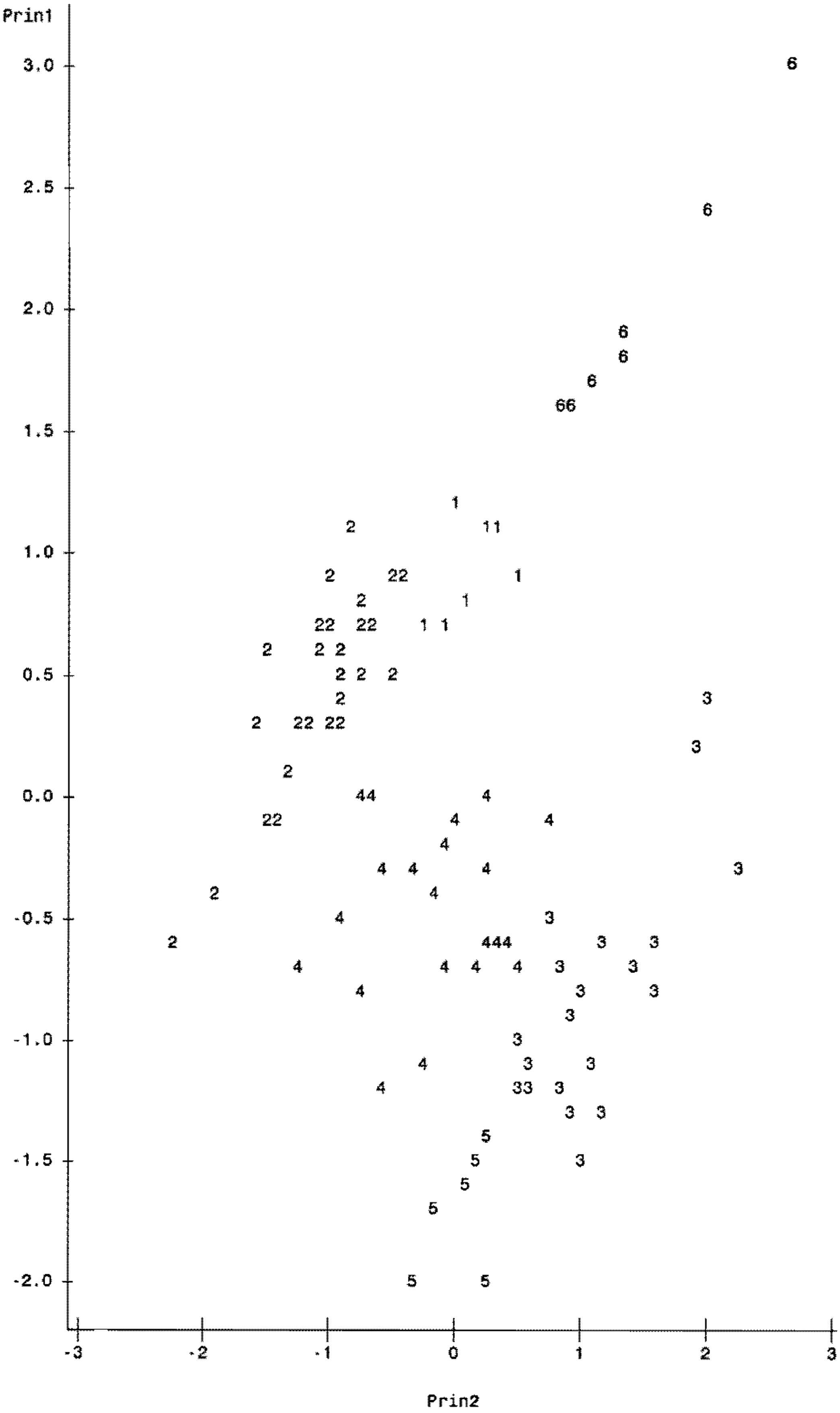
Cluster	Total C (ton/ha/1m) **Min-Max (Mean)**	Stable C (ton/ha/1m) **Min-Max (Mean)**	Sampling Points in the group
6 (N=5)	**312-414 (357)**	**93-230 (159)**	**Forest B1 (4)** **Imp Past B1 (1)**
2 (N= 15)	**195-301 (248)**	**53-118 (82)**	Forest B1 (8), Imp Past B1 (5), Forage Bank B1 (2),
5 (N=19)	**101-238 (176)**	**42-100 (61)**	**All in Block 2** **Forest (3), Imp Past (7), Degr Past (9)**
1(N=18)	**147-206 (167)**	**48-99 (69)**	**All in Block 1** **Imp Past (6), Degr Past (4), Forage Bank B1 (8)**
4 (N=22)	**101-209 (159)**	**11-107 (47)**	**Degr Past B1 (3), Forest B2 (9), Imp Past B2 (5), Degr Past B2 (3), Forage Bank B2 (2)**
3 (N=14)	**60-139 (113)**	**12-61 (41)**	**F. Bank B1-B2 (9)** **Degr P B1 (5)**

Plot of Prin1*Prin2. Symbol is value of CLUSTER.



NOTE: 5 obs hidden.

6 CLUSTER GROUPS,R2=82%



NOTE: 6 obs hidden.

Table 9: Grouping of sampling points according to first two Principal Components at 1m-equiv depth. Farm blocks 1 and 2,

Andean Hillsides, Colombia. N= 93, Cluster R2 =82 %

Classification Criteria	**CLUSTER NO.**					
	1 **N=9**	**2** **N=30**	**3** **N=20**	**4** **N=21**	**5** **N=6**	**6** **N=7**
Principal Components	**Cluster Means**					
PC1	0.97 H	0.46 M	-0.83 M	-0.46 L	-1.71 L	2 L
PC2	0.17 H	-1.03 M	1.13 M	-0.17 M	0.04 L	1.45 L
Original Soil parameters	***Cluster Means***					
Total C (ton/ha/1m-equiv)	189	124	162	129	111	275
Stable C (ton/ha/1m-equiv)	59	47	49	42	22	96
Total N (ton/ha/1m-equiv)	15.65	8.73	19	10	7	21
Sand (ton/ha/1m-equiv)	2499	2724	1382	2040	1274	2945
Clay (ton/ha/1m-equiv)	1481	1415	4613	3353	4696	1357
CEC (ton/ha/1m-equiv)	128	137	145	165	159	157
pH (mean)	6.08	6.19	5.20	5.7	5.2	5.9

Table 8c: Association between Soil and Carbon variables at 40-100cm-equiv: Principal Component Analysis.

Variance explained: 79.41 %

Variable	PC_1 (57.72%)	PC_2 (21.69%)
Total C (ton/ha/40-100cm-equiv)	0.48*	-0.040
Total N (ton/ha/40-100cm-equiv)	0.41*	-0.065
Stable C (ton/ha/40-100cm-equiv)	0.42*	0.13
Sand (ton/ha/40-100cm-equiv)	0.42*	0.26
Clay (ton/ha/40-100cm-equiv)	0.23	-0.61*
pH (mean in 4-100 cm-equiv)	0.41	0.70*
CEC (ton/ha/40-100cm-equiv)	0.43*	-015

PC1: Total and Stable C, total N and predominance of sand
PC2: Soil texture and acidity

Table 8b: Association between Soil and Carbon variables at 1m-equiv: Principal Component Analysis.

Variance explained 86.9 %

Variable	PC_1 (39.77%)	PC_2 (30.66%)	PC_3 (16.53%)
Total C (ton/ha/1m-equiv)	0.36	0.49*	0.045
Total N (ton/ha/1m-equiv)	0.26	0.50*	0.13
Stable C (ton/ha/1m-equiv)	0.43*	0.35	-0.065
Sand (ton/ha/1m-equiv)	0.43*	-0.31	0.37
Clay (ton/ha/1m-equiv)	-0.49*	0.34	0.008
pH (mean in 1m-equiv)	0.39	-0.39	-0.21
CEC(ton/ha/1m-equiv)	-0.10	-0.043	0.88*

PC1: Stable C with predominance of sand over clay
PC2: Total C and total N
PC3: CEC

Table 1. Dry matter (DM) production (kg.ha^{-1}) of *Brachiaria* alone or associated with *Arachis pintoi* in a slope topography ("Balkanes") in the Amazonian piedmont. Means adjusted to 90 days of regrowth for four sampling dates during 2004

Component	**Brachiaria**				**Brachiaria + Arachis**			
	290104	**220404**	**120804**	**41104**	**290104**	**220404**	**120804**	**41104**
Main Grass	3083	2854	4069.2	3130.6	2362.6	2361	3702.6	3159.4
Other Grasses	65	569.6	47.4	84.2	150	228.2	69.6	239.4
Legume	0.6	0.63	2.4	13.4	820.2	1406.8	902	1355.6
Weeds	140.4	101.8	88.8	284.2	33	28.2	21	32.8
Total DM	3289	3526	4207.08	3512.4	3365.8	4024.2	4695.2	4787.2

Table 2. Dry matter (DM) production (kg.ha^{-1}) of *Brachiaria* alone or associated with *Arachis pintoi* in a flat topography ("Santo Domingo") in the Amazonian piedmont. Means adjusted to 90 days of regrowth for three sampling dates during 2004

Component	**Brachiaria**			**Brachiaria + Arachis**		
	40304	**170604**	**200904**	**40304**	**170604**	**200904**
Main Grass	1840.6	2193	1808.8	1403	2298	1892.4
Other Grasses	28.8	51.6	80	150.8	118.4	225.8
Legume	5.2	17.4	67.8	385.2	400.2	957.8
Weeds	0	7.4	18.2	5.2	18.2	26
Total DM	1874.6	2269.4	3949.6	1944.2	2834.8	3102

Table 3 shows the comparison of the dry matter production for each component in the two topographies. Unexpectedly, total dry matter was 78% and 60% higher in Balkanes than in Santo Domingo, respectively for the plots with *Brachiaria* alone or in association with *A. Pintoi*.

Dry matter production of the main grass in the grass alone plots was 68% higher in the slope topography than in the flat ones, and 55% higher in the associated plots. Similarly, dry matter yield of *Arachis pintoi* was 93% higher in Balkanes (slope) than in Santo Domingo (flat).

The unexpected higher yields in the slope topography are not yet fully understood, however, a chemical analysis indicates that the soil in Santo Domingo has lower contents of both mayor and minor elements.

Results of Forage Evaluation During 2004

Jaime E. Velasquez-R and Jader Muñoz-Ramos

Introduction

As part of the previously planned "Objective 7" (Work Plan 2002), during 2003 an experiment in small plots was established with an improved Brachiaria sp. from the CIAT collection. The aim is to determine the biomass production of the specie planted alone or in association with *Arachis pintoi*, and to compare the botanical composition with a plot which have the original vegetation, in two types of topographies (slope and flat). Treatments were allocated to plots of 20 m x 10 m, in a Complete Randomized Block Design with four replications.

The experiment is being carried out in two farms of the Universidad de la Amazonia: Balkanes (slope) and Santo Domingo (flat).

During 2004, seven samples (four at Balkanes and three at Santo Domingo) were taken by using a 1.0 m x 0.5 m frame thrown at random five times within each plot. Grass was cut at 20 cm from the ground whilst the legume was cut at ground level. Each frame was separated in four components: main grass, other grasses, legume and weeds, and weighed individually. Pooled subsamples of about 200 g, where available for each component, were dried at 80 °C for 72 h, and the dry matter determined.

The bare soil and the botanical composition, as a percentage of the visually observed biomass, was estimated in each frame before cutting.

After sampling, the whole plot was cut down to 20 cm and 30 % of the green material is spread in the whole area.

Results

Tables 1 and 2 show the mean dry matter production ($kg.ha^{-1}$) of the grass alone or associated with *A. Pintoi*, respectively for the slope and flat topographies. For the four sampling dates, values have been adjusted to 90 days of regrowth, assuming linear growth.

In general, there is a trend of increasing total dry matter production from January to September. This is probably associated to the increased rainfall during that period.

Total dry matter production in the grass-legume plots was 16% higher than in the grass alone plots, in Balkanes, but no effect of the legume was found in Santo Domingo.

Sin embargo las deficiencias en elementos menores, en el bloque plano eran mucho más críticas que en el bloque pendiente, debido posiblemente a la mayor intensidad en el uso del suelo en esta región plana más cercana a la capital del Departamento del Caquetá. Esta situación fue detectada en el transcurso de las mediciones y se decidió aplicar después de cada corte una dosis de 5 gramos de triple 15 y 2 gramos de granum completo (microelementos). Se espera con este tratamiento superar la dificultad y a futuro lograr una producción estable en este bloque. En la Tabla No 1 se muestran los contenidos iniciales de elementos menores deficientes en el suelo del bloque plano.

Tabla 1. Reportes de concentraciones de elementos menores en una muestra de suelo procedente del bloque plano- Granja Santo Domingo.

Descripción	*Santo Domingo (bloque plano)*
Ca (meq)	*0.13*
Mg (meq)	*0.06*
Al (meq)	*3.12*
Cu (ppm)	*0.33*
Fe (ppm)	*72.2*
Mn (ppm)	*2.61*
Zn (ppm)	*0.55*
B (ppm)	*0.36*

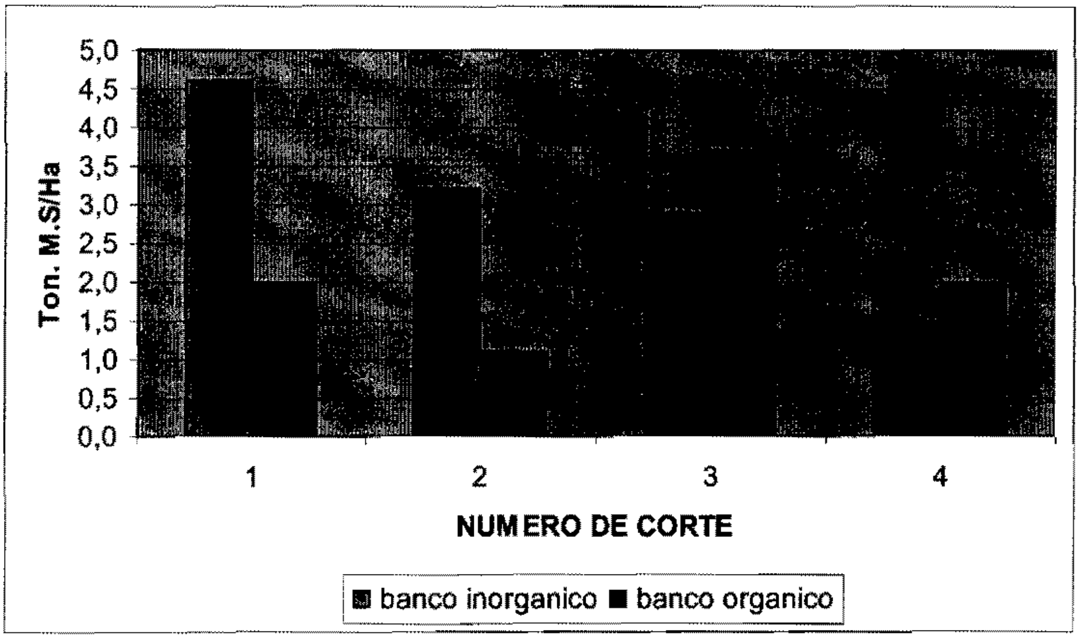
5. Control de plagas.

En el mes de octubre del 2003, un año después de la siembra se presentó en el T3 un ataque de gusano cogollero o churrasco que atacó las plantas. El procedimiento que se realizó consistió en cosechar el forraje de todas las plantas (tercer corte de uniformización) y a continuación fumigar todas las 4 parcelas con un preparado de ajo; lo cual dio magnífico resultado. Así mismo se utilizó una fumigación con Bacillus turigensis para combatir un cucharón que afectó el cogollo del bohío (***Clitoria farchildiana***)

3. Producción de biomasa de bancos de proteína con fertilización inorgánica y orgánica.

Al comparar las producciones de biomasa de los bancos que reciben fertilización orgánica y aquellos que solo reciben abono orgánico preparado en la finca, se puede analizar que las especies que recibieron abono orgánico no tuvieron una respuesta inmediata al abonamiento, sin embargo, el paso de reconversión del suelo por efecto de los microorganismos biológicos es un proceso a mediano y largo plazo que ya comienza a dar resultados, expresados en una mayor producción de hojas y tallos tiernos con destino a la alimentación de los animales de la finca. (Ver gráfica 4)

Grafica 4: Comparación de la Producción Total de Biomasa por Corte en Bancos Proteína con Diferente Manejo de Fertilización Expresados en Base Seca. (Ton/ha)



4. Producción de biomasa de bancos mixtos de proteína con manejo de fertilización química establecidos en el bloque plano – Granja Santo Domingo.

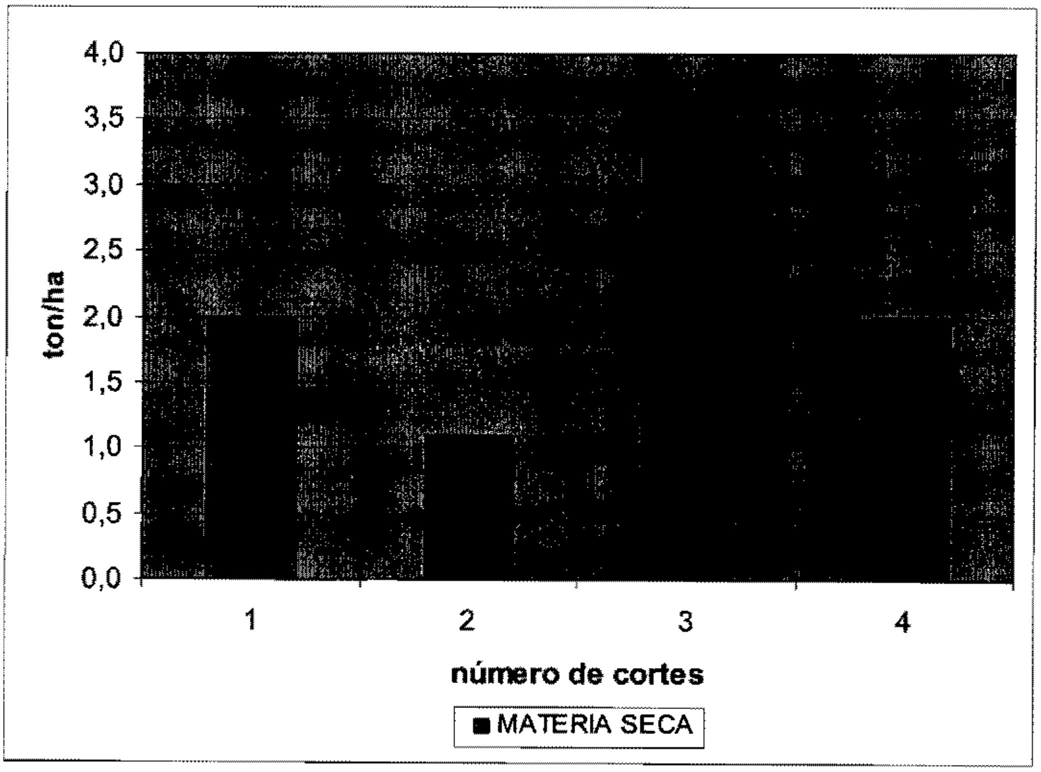
Los bancos de proteína establecidos en el bloque plano en la granja Santo Domingo, solamente se les ha podido realizar dos cortes durante el año 2004, debido a que han tenido un desarrollo muy pobre y un periodo de recuperación muy lento. El primer corte fue realizado en febrero de 2004 y el segundo corto solo pudo realizarse en agosto del mismo año, debido a que las plantas presentaban síntomas claros de atraso. Las causas de este comportamiento, se deben principalmente a las condiciones físicas, químicas y biológicas iniciales del suelo; las cuales fueron corregidas enfrentando las deficiencias iniciales de elementos mayores, que hacen referencia a nitrógeno, fosforo y potasio, también como, a la reducción de la acidez del suelo.

2. Producción de biomasa de bancos mixtos de proteína con manejo de fertilización orgánica en el bloque pendiente – Granja Balcanes.

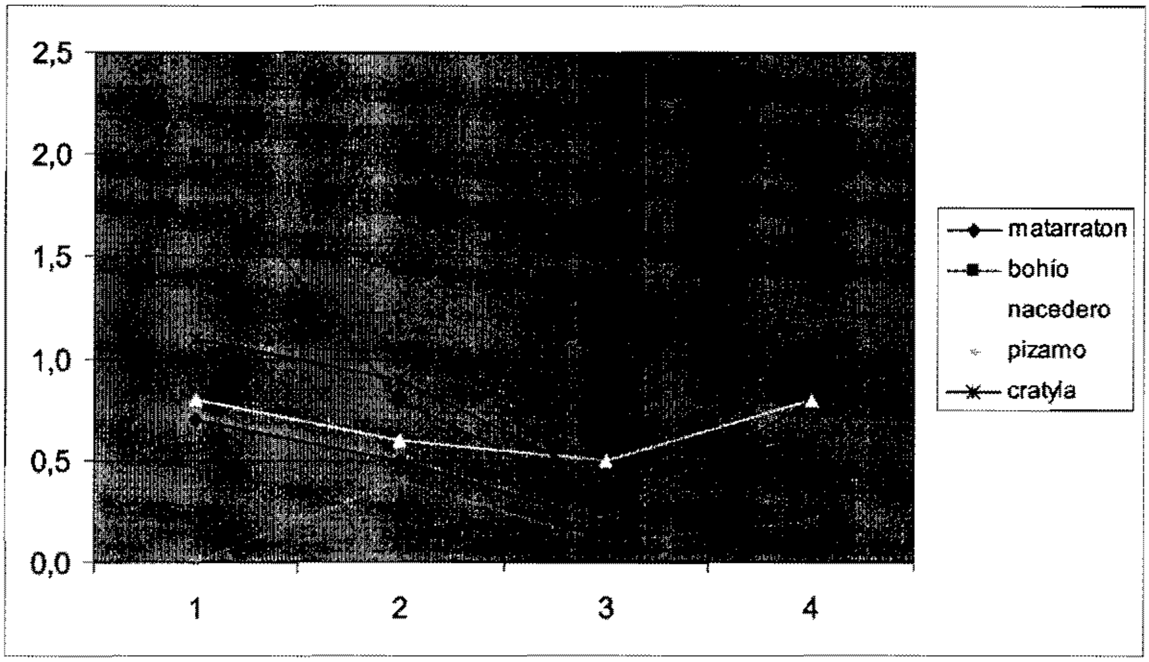
Los bancos que recibieron fertilización orgánica, establecidos en el bloque pendiente de la Granja Balcanes de propiedad de la Universidad de la Amazonia (Ver gráfica 3), presentaron menor producción de biomasa durante los dos primeros cortes, comparados con los bancos que recibieron fertilización inorgánica; sin embargo, en el tercer corte esta cifra se incremento, superando el valor del banco inorgánico en 0,8 toneladas de M.S/Ha. Esta condición se mantiene en el cuarto corte con una diferencia de 0,5 toneladas de M.S, de los bancos que reciben triple quince y urea como fertilizante.

El abono orgánico que es aplicado a estos bancos es preparado en la misma finca, utilizando forrajes sobrantes de la propiedad y fermentado con gallinaza, miel de purga, levadura como fermento, cal dolomítica y fosforita huila. El proceso tarda aproximadamente cuatro semanas en descomposición y es volteado a pala cada tres días y rociado con agua para conservar la humedad necesaria.

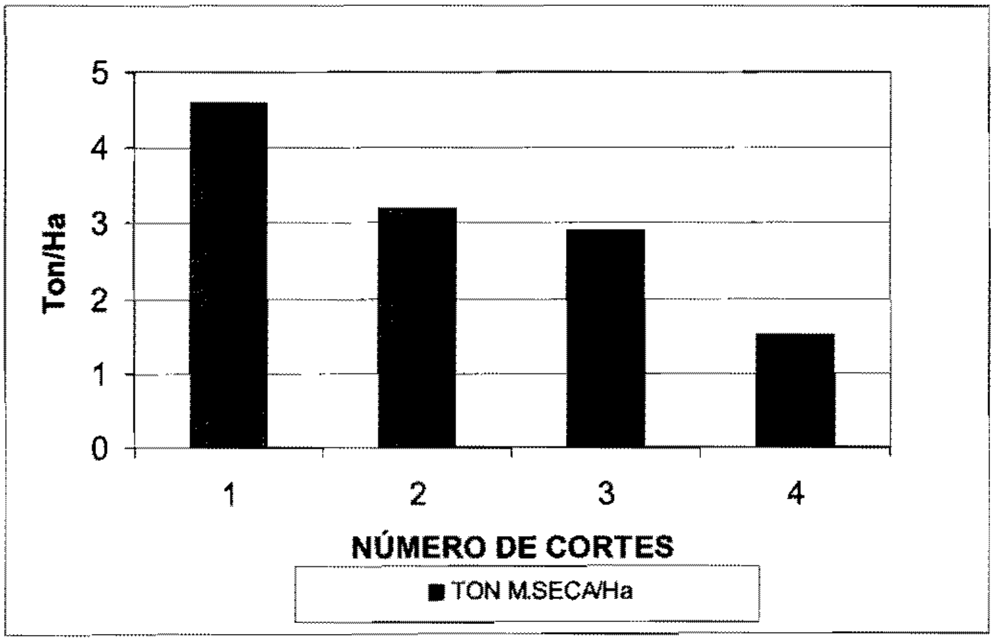
Grafica 3: Producción Total de Biomasa por Corte en Bancos Proteína con Fertilización Organica Expresados en Base Seca. (Ton/ha)



Grafica 1: Producción de Biomasa por Especie Arbórea en Bancos de Proteína con Fertilización Inorgánica Expresados en Base Seca. (Ton/ha)



Grafica 2: Producción Total de Biomasa por Corte en Bancos Proteína con Fertilización Inorganica Expresados en Base Seca. (Ton/ha)



Las plantas han presentado un desarrollo variado en cada corte, se obtuvo mayor producción en el primer corte, lo cual se considera acertado, debido a que las plantas están aprovechando todas las ventajas derivadas de la preparación inicial del suelo.

A continuación se presenta el resultado consolidado de la producción de biomasa durante los cuatro cortes realizados durante el año 2004. Estos resultados se expresan en toneladas de materia seca por hectárea, tanto para los bancos que reciben fertilización inorgánica, como aquellos que solo reciben abono orgánico después de cada corte.

1. Producción de biomasa de bancos mixtos de proteína con manejo de fertilización química en el bloque pendiente – Granja Balcanes.

La producción de biomasa de las cinco especies forrajeras evaluadas ha mantenido un comportamiento similar, con excepción del bohío que tuvo un desarrollo muy alto en comparación a las otras cuatro especies como resultado del primer corte y que posteriormente descendió producto del ataque de una plaga, la cual se ha controlado con bacillus turigensis. Igualmente, el pizamo (***Erithryna fusca***) ha presentado problemas de prendimiento y su desarrollo no ha sido semejante a las otras especies.

La producción promedia en los cuatro cortes realizados durante el año 2004 fue de 0.6 toneladas de materia seca por hectárea, destacándose la producción promedia de biomasa del bohío (***Clitoria farchildiana***) de 0,9 toneladas de materia seca/ha, seguida de la especie ***Cratylia argentea***, la cual presentó una producción promedia de 0,8 toneladas de materia seca/ha.

En la gráfica No1 puede observarse una producción máxima de 2 ton/ha correspondiente a la primera producción del bohío y una producción mínima de 0 toneladas para el pízamo en el mismo periodo. La especie que mantuvo un rendimiento promedio durante el periodo de corte fue el nacedero (***Trichantera gigantea***), a pesar de ser una especie que tardó mucho tiempo en su proceso de establecimiento.

La producción total en base seca de biomasa de bancos mixtos de proteína expresados en toneladas por hectárea a partir de fertilización inorgánica con triple 15 se muestra en la grafica 2, puede apreciarse un descenso en la producción del primer al cuarto corte, situación debida posiblemente a una mayor necesidad de nutrientes durante el crecimiento de las plantas y al estrés ocasionado por el mayor periodo de precipitación presentado en la región durante los meses de mayo a octubre.

Reporte de Avance en el Bosque Húmedo Tropical de América Amazonia Colombiana

Junio 1 – Nov 30, 2004

Producción de Biomasa de Bancos de Proteína

Ramírez, Bertha Leonor y Suárez Juan Carlos.

Introducción.

El desarrollo de los nuevos experimentos al interior del proyecto de investigación para la evaluación de la capacidad de captura de carbono en sistemas productivos del ecosistema de bosque tropical de América, comprende el establecimiento y manejo de bancos mixtos de proteína para corte y acarreo, basados en el desarrollo de especies arbóreas las cuales fueron establecidas en Octubre de 2002, efectuados dos cortes de uniformización durante el año 2003 e inició el muestreo de evaluación de la producción de biomasa a partir de enero de 2004.

El objetivo de la investigación consiste las evaluaciones sobre nuevas pequeñas parcelas experimentales, establecidas a partir de pasturas degradadas, con el fin de comparar en el corto plazo, los niveles de acumulación de carbono del sistema mejorado contra la pastura degradada; así mismo, determinar el beneficio que estos sistemas de uso del suelo puedan tener para el productor, reflejados en una mayor producción de forraje, incremento de la biodiversidad vegetal de la finca, oferta de forraje de alta calidad para los animales, etc.

Las parcelas experimentales de bancos mixtos de proteína fueron establecidas en dos bloques, pendiente y plano en la región de la Amazonia colombiana. El sistema de manejo de los bancos se encuentra dividido en dos tratamientos, fertilización inorgánica y fertilización orgánica. El proceso de establecimiento, así como, las características biofísicas de la región y las condiciones iniciales del suelo se encuentran especificadas en un informe anterior.

El diseño de las parcelas experimentales fue establecido obedeciendo el diseño experimental de cuadrado latino con cuatro tratamientos y cuatro réplicas por tratamiento, establecido en dos bloques, pendiente (granja Balcanes) y plano (granja Santo Domingo). Adicionalmente, cuenta con un tratamiento adicional de banco de proteína manejado de acuerdo con las condiciones especiales de los campesinos y la aplicación de abono orgánico.

Las especies arbóreas son cortadas con intervalos de tres meses, procediendo a retirar todas las hojas y tallos tiernos, dejando únicamente el tronco principal de la planta. Después de cada corte y de acuerdo con el tratamiento establecido, las parcelas son abonadas.

Annex 5

Advancement Report June 1 – November 30, 2004, Tropical Humid Forest Amazonia, Colombia

Relationship between SCS (Y) and Root Biomass (X)
First C-Sampling, (Feb – May, 2002)
Andean Hillsides, Colombia

Site 1 : Dovio				
Y	**Intercept**	**Slope**	**R² (%)**	**Signif. Prob.**
Total C (ton/ha/0-40 cm)	12,2	0.03	1.5	NS
Oxidisable C (ton/ha/0-40 cm)	10.2	-0.00	0.03	NS
Stable C (ton/ha/0-40 cm)	2.1	0.03	8.6	NS
Total C (ton/ha/40-100 cm)	6.6	0.01	0.8	NS
Oxidisable C (ton/ha/40-100 cm)	5.1	-0.01	1.3	NS
Stable C (ton/ha/40-100 cm)	1.6	0.02	5.5	NS
Total C (ton/ha/1m)	187.7	0.47	1.6	NS
Oxidisable C (ton/ha/1m)	152.8	-0.14	0.4	NS
Stable C (ton/ha/1m)	36.5	0.56	10.5	NS

Site 2: Dagua				
Y	**Intercept**	**Slope**	**R² (%)**	**Signif. Prob.**
Total C (ton/ha/0-40 cm)	8.7	0.04	9.7	NS
Oxidisable C (ton/ha/0-40 cm)	6.6	0.04	16.8	NS
Stable C (ton/ha/0-40 cm)	2.2	0.01	0.7	NS
Total C (ton/ha/40-100 cm)	5.9	0.00	0.4	NS
Oxidisable C (ton/ha/40-100 cm)	2.4	0.00	6.2	NS
Stable C (ton/ha/40-100 cm)	3.3	0.00	2.0	NS
Total C (ton/ha/1m)	145.9	0.48	4.8	NS
Oxidisable C (ton/ha/1m)	90.0	0.75	12.7	NS
Stable C (ton/ha/1m)	54.3	-0.07	0.3	NS

B. P. Alto	1	0-10	0.5176	5.1756	3	17.490158	10.969483	62.72	12	6.36917	8.26111	129.70
		*10-20	0.1673	1.6729	3	1.701648	0.857993	50.42	12	0.85153	0.74722	87.75
		20-40	0.0242	0.2415	3	0.499461	0.225998	45.25	12	0.30404	0.22316	73.40
		40-100	0.0212	0.2123	3	0.157614	0.093027	59.02	12	0.15657	0.14599	93.24
	2	0-10	0.2514	2.5142	3	1.435390	0.934816	65.13				
		*10-20	0.0753	0.7532	3	0.582966	0.151478	25.98				
		20-40	0.0094	0.0943	3	0.179176	0.134382	75.00				
		40-100	0.0365	0.3654	3	0.152835	0.184113	120.47				
	3	0-10	0.2342	2.3423	3	3.438718	1.717613	49.95				
		*10-20	0.0374	0.3744	3	0.546868	0.463328	84.72				
		20-40	0.0193	0.1934	3	0.157503	0.056582	35.92				
		40-100	0.0000	0.0000	3	0.190022	0.261055	137.38				
	4	0-10	0.3478	3.4780	3	3.112427	0.616844	19.82				
		*10-20	0.0102	0.1024	3	0.574640	0.806629	140.37				
		20-40	0.0100	0.1000	3	0.380027	0.282895	74.44				
		40-100	0.0193	0.1931	3	0.125804	0.058273	46.32				
Suelo Degradado	1	0-10	0.0432	0.4317	3	0.293808	0.125252	42.63	12	2.20410	2.03455	92.31
		*10-20	0.0243	0.2433	3	0.136225	0.092766	68.10	12	0.42439	0.32470	76.51
		20-40	0.0085	0.0850	3	0.098654	0.064895	65.78	12	0.16775	0.13266	79.08
		40-100	0.0000	0.0000	3	0.025345	0.043898	173.21	12	0.10510	0.16281	154.91
	2	0-10	0.0502	0.5015	3	0.738515	0.624223	84.52				
		*10-20	0.0085	0.0846	3	0.198372	0.127099	64.07				
		20-40	0.0000	0.0000	3	0.056815	0.049425	86.99				
		40-100	0.0000	0.0000	3	0.013464	0.023320	173.21				
	3	0-10	0.3166	3.1663	3	4.358411	1.621534	37.20				
		*10-20	0.0510	0.5103	3	0.760302	0.266949	35.11				
		20-40	0.0265	0.2653	3	0.322068	0.107587	33.41				
		40-100	0.0505	0.5054	3	0.353617	0.131419	37.16				
	4	0-10	0.1919	1.9192	3	3.425658	1.355149	39.56				
		*10-20	0.0451	0.4512	3	0.602660	0.256413	42.55				
		20-40	0.0082	0.0818	3	0.193449	0.127398	65.86				
		40-100	0.0000	0.0000	3	0.027969	0.048444	173.21				

Bosque S. A.	1	0-10	0.5914	5.9142	3	13.620272	6.822190	50.09	12	4.47557	6.32193	141.25
		*10-20	0.2124	2.1240	3	3.096535	1.362859	44.01	12	1.05254	1.39734	132.76
		20-40	0.2449	2.4488	3	1.663754	1.335494	80.27	12	0.70614	1.03719	146.88
		40-100	0.0036	0.0365	3	0.222247	0.317340	142.79	12	0.08886	0.16422	184.81
	2	0-10	0.4361	4.3615	3	2.014805	2.082060	103.34				
		*10-20	0.0593	0.5932	3	0.780204	0.364059	46.66				
		20-40	0.0227	0.2269	3	0.906297	1.292610	142.63				
		40-100	0.0000	0.0000	3	0.000000	0.000000	0.00				
	3	0-10	0.1296	1.2961	3	1.651985	0.312289	18.90				
		*10-20	0.0244	0.2437	3	0.167097	0.067275	40.26				
		20-40	0.0297	0.2970	3	0.174326	0.115849	66.46				
		40-100	0.0130	0.1295	3	0.080452	0.070230	87.29				
	4	0-10	0.0720	0.7204	3	0.615217	0.094466	15.35				
		*10-20	0.0106	0.1063	3	0.166343	0.111619	67.10				
		20-40	0.0109	0.1089	3	0.080194	0.035793	44.63				
		40-100	0.0081	0.0813	3	0.052742	0.045726	86.70				
Banco Mixto	1	0-10	0.1482	1.4823	3	5.590151	4.092166	73.20	9	3.10956	3.12935	100.64
		*10-20	0.0596	0.5964	3	0.928185	0.704848	75.94	9	0.87668	1.01937	116.28
		20-40	0.0376	0.3761	3	0.362823	0.012311	3.39	9	0.39161	0.38439	98.16
		40-100	0.0078	0.0776	3	0.211583	0.222248	105.04	9	0.17857	0.16743	93.76
	2	0-10	0.1164	1.1644	3	2.683805	2.458654	91.61				
		*10-20	0.0373	0.3732	3	1.356659	1.691073	124.65				
		20-40	0.0209	0.2092	3	0.590791	0.695527	117.73				
		40-100	0.0182	0.1823	3	0.240397	0.185694	77.24				
	3	0-10	0.1619	1.6186	3	1.054724	0.738307	70.00				
		*10-20	0.0310	0.3103	3	0.345204	0.163353	47.32				
		20-40	0.0196	0.1958	3	0.221204	0.053011	23.96				
		40-100	0.0000	0.0000	3	0.083729	0.085970	102.68				

Cálculo Estadísticas Descriptivas Raíces Dagua (gr de raíces/Kg de suelo)

Tratamiento	Calicata	Profundidad cm	Raices %	Raices (gr de raices/Kg suelo)	Profundidad/Calicata				Profundidad/Tratamiento			
					n	Media	Desviación Estándar	Coeficiente Variación	n	Media	Desviación Estándar	Coeficiente Variación
Pastura Degradada	1	0-10	1.1589	11.5885	3	8.050630	3.530033	43.85	12	5.88778	3.89232	66.11
		*10-20	0.1972	1.9724	3	1.358874	0.535561	39.41	12	1.15693	0.42440	36.68
		20-40	0.0167	0.1672	3	0.320379	0.191787	59.86	12	0.29355	0.16385	55.82
		40-100	0.0041	0.0412	3	0.026849	0.023270	86.67	12	0.09585	0.07905	82.47
	2	0-10	0.2708	2.7078	3	2.536645	0.408509	16.10				
		*10-20	0.1013	1.0129	3	1.024663	0.486009	47.43				
		20-40	0.0311	0.3111	3	0.199861	0.107544	53.81				
		40-100	0.0049	0.0494	3	0.067805	0.030954	45.65				
	3	0-10	0.2144	2.1439	3	4.200982	2.637913	62.79				
		*10-20	0.0623	0.6234	3	0.921328	0.306929	33.31				
		20-40	0.0266	0.2657	3	0.289469	0.051850	17.91				
		40-100	0.0043	0.0433	3	0.132884	0.117844	88.68				
	4	0-10	0.3850	3.8503	3	8.762844	4.817709	54.98				
		*10-20	0.0892	0.8915	3	1.322867	0.401789	30.37				
		20-40	0.0090	0.0902	3	0.364487	0.273513	75.04				
		40-100	0.0091	0.0906	3	0.155861	0.056550	36.28				
Pastura Mejorada	1	0-10	1.0286	10.2856	3	16.261527	6.842539	42.08	12	15.16014	8.85417	58.40
		*10-20	0.4724	4.7239	3	5.297883	2.409606	45.48	12	3.75457	1.61071	42.90
		20-40	0.1762	1.7615	3	1.741107	0.155390	8.92	12	1.31429	0.65424	49.78
		40-100	0.0738	0.7385	3	0.326757	0.359050	109.88	12	0.29104	0.26024	89.42
	2	0-10	1.9954	19.9540	3	13.895182	5.255210	37.82				
		*10-20	0.4272	4.2716	3	3.403495	0.955966	28.09				
		20-40	0.0834	0.8344	3	0.763649	0.066824	8.75				
		40-100	0.0166	0.1656	3	0.275948	0.264000	95.67				
	3	0-10	1.1715	11.7152	3	6.375900	4.625145	72.54				
		*10-20	0.3561	3.5610	3	3.175067	0.637684	20.08				
		20-40	0.2941	2.9412	3	1.634761	1.132441	69.27				
		40-100	0.0662	0.6623	3	0.250731	0.359257	143.28				
	4	0-10	3.0559	30.5595	3	24.107946	9.761747	40.49				
		*10-20	0.4775	4.7749	3	3.141852	1.522473	48.46				
		20-40	0.1457	1.4570	3	1.117651	0.320952	28.72				
		40-100	0.0514	0.5141	3	0.310708	0.198826	63.99				

Banco Mixto	1	0-10	3	2.326415	1.310157	56.32	12	11.37394	19.68283	173.05
		*10-20	3	0.782308	0.205012	26.21	12	0.94582	1.13060	119.54
		20-40	3	0.215817	0.075235	34.86	12	0.54126	0.88981	164.40
		40-100	3	0.143549	0.103069	71.80	12	0.22994	0.22117	96.19
	2	0-10	3	4.205336	5.258532	125.04				
		*10-20	3	1.112504	1.034824	93.02				
		20-40	3	0.260949	0.138964	53.25				
		40-100	3	0.070827	0.069622	98.30				
	3	0-10	3	5.164261	1.629037	31.54				
		*10-20	3	0.298041	0.138959	46.62				
		20-40	3	0.168174	0.051027	30.34				
		40-100	3	0.213389	0.127309	59.66				
	4	0-10	3	33.799731	32.964676	97.53				
		*10-20	3	1.590439	2.136293	134.32				
		20-40	3	1.520094	1.550634	102.01				
		40-100	3	0.491996	0.291156	59.18				
Bosque	1	0-10	3	4.554764	0.530443	11.65	12	7.07146	4.82121	68.18
		*10-20	3	3.134701	1.959968	62.52	12	4.36275	4.30821	98.75
		20-40	3	2.205974	1.205708	54.66	12	1.46835	1.53384	104.46
		40-100	3	0.458379	0.566782	123.65	12	0.16951	0.30135	177.78
	2	0-10	3	14.503405	1.256917	8.67				
		*10-20	3	10.966294	2.438614	22.24				
		20-40	3	2.642229	2.376611	89.95				
		40-100	3	0.061069	0.014780	24.20				
	3	0-10	3	3.264743	0.879521	26.94				
		*10-20	3	1.975629	1.075929	54.46				
		20-40	3	0.660818	0.185424	28.06				
		40-100	3	0.129859	0.025423	19.58				
	4	0-10	3	5.962920	3.045682	51.08				
		*10-20	3	1.374364	1.233849	89.78				
		20-40	3	0.364380	0.337478	92.62				
		40-100	3	0.028728	0.049759	173.21				

Cálculo Estadísticas Descriptivas Raíces Dovio (gr de raíces/Kg de suelo)

Tratamiento	Calicata	Profundidad cm	Profundidad/Calicata				Profundidad/Tratamiento			
			n	Media	Desviación Estándar	Coeficiente Variación	n	Media	Desviación Estándar	Coeficiente Variación
Pastura Degradada	1	0-10	3	7.696708	1.903976	24.74	12	5.19512	2.22537	42.84
		*10-20	3	2.160252	0.401603	18.59	12	1.99770	0.61169	30.62
		20-40	3	0.697109	0.227460	32.63	12	0.63819	0.29359	46.00
		40-100	3	0.606368	0.511575	84.37	12	0.36565	0.35140	96.10
	2	0-10	3	4.758641	1.073255	22.55				
		*10-20	3	1.832890	0.502118	27.39				
		20-40	3	0.611948	0.472157	77.16				
		40-100	3	0.234284	0.114141	48.72				
	3	0-10	3	5.273686	2.231683	42.32				
		*10-20	3	2.593692	0.504199	19.44				
		20-40	3	0.657546	0.424350	64.54				
		40-100	3	0.548779	0.336136	61.25				
	4	0-10	3	3.051428	0.951336	31.18				
		*10-20	3	1.403964	0.498275	35.49				
		20-40	3	0.586151	0.092031	15.70				
		40-100	3	0.073158	0.001826	2.50				
Pastura Mejorada	1	0-10	3	4.389776	1.486614	33.87	12	5.19992	2.59332	49.87
		*10-20	3	1.068334	0.225530	21.11	12	1.19118	0.53535	44.94
		20-40	3	0.385903	0.319167	82.71	12	0.43670	0.17915	41.02
		40-100	3	0.101918	0.018566	18.22	12	0.07737	0.02260	29.21
	2	0-10	3	6.279677	5.028665	80.08				
		*10-20	3	0.808575	0.330579	40.88				
		20-40	3	0.444741	0.138229	31.08				
		40-100	3	0.061009	0.019167	31.42				
	3	0-10	3	5.519333	2.262052	40.98				
		*10-20	3	0.958121	0.330435	34.49				
		20-40	3	0.434819	0.175861	40.44				
		40-100	3	0.080918	0.006962	8.60				
	4	0-10	3	4.610878	0.983921	21.34				
		*10-20	3	1.929703	0.406360	21.06				
		20-40	3	0.481357	0.132892	27.61				
		40-100	3	0.065631	0.022740	34.65				

Annex 4.2

Root Biomass and its Relation with SCS Andean Hillsides, Colombia. First C-Sampling (Feb-May, 2004)

- Root Biomass data per site x System x Depth
- Relationship between SCS and Root Biomass

Table 10: C-level per Cluster and Cluster members. Farm blocks 1 and 2, Andean Hillsides, Colombia. N=93 sampling points; No. Clusters = 6; R^2=82 %

Cluster	Total C (ton/ha/1m-equiv) **Min-Max (Mean)**	Stable C (ton/ha/1m-equiv) **Min-Max (Mean)**	Sampling Points in the group
6 (N=7)	**253-332 (275)**	**73-138 (96)**	**Forest B1 (7)**
1 (N= 9)	**156-288 (189)**	**40-88 (59)**	**Forest B1 (5),** **Imp Past B1(2),** **All in Block 2**
3 (N=20)	**120-234 (162)**	**30-90 (49)**	**Forest (5), Imp Past (7), Degr Past (8)**
4(N=21)	**73-176 (129)**	**13-88 (42)**	**Degr Past B1 - B2 (6), F. Bank B1-B2 (8), Forest B2 (5), Imp Past B2(2),**
2 (N=30)	**54-157 (123)**	**11-71 (47)**	**Degr Past B1 (9), F. Bank B1 - B2 (11)** **All in Block 2**
5 (N=6)	**83-139 (111)**	**11-38 (22)**	**Forest (2), Imp Past (3), Degr Past (1)**

The Netherlands Cooperation Activity CO-010402

Research Network for the Evaluation of Carbon Sequestration Capacity of Pasture, Agropastoral and Silvopastoral Systems in the American Tropical Forest Ecosystem

CIPAV- U. Amazonia -CIAT-CATIE-W. University

Project duration: 5 years
December 1, 2001 – November 30, 2006

FIFTH INTERNATIONAL COORDINATION MEETING

Punta Leona, Costa Rica, July 26-29, 2004

CIPAV: Centre for Research on Sustainable Agricultural Production Systems, Cali, Colombia.
Universidad de la Amazonia, Florencia, Colombia.
CIAT: International Centre for Tropical Agriculture, Cali, Colombia.
CATIE: Centro Agronómico Tropical para Capacitación y Enseñanza, Turrialba, Costa Rica.
Wageningen University and Research Centre, Wageningen, The Netherlands.

Annex 8

Program and Recommendations
Fifth International Coordination Meeting
Punta Leona, Costa Rica, July 26-29, 2004

Tabla 5. Gramos de raíces M.S por kg de suelo en sistemas establecidos en el Dagua

Tratamiento	**Profundidad cm**	**gr Raíces/kg suelo Media**	**D.E**	**C.V**
Suelo Deg.	0-10	2,20	2,03	92,31
	10-20	0,42	0,32	76,51
	20-40	0,17	0,13	79,08
	40-100	0,11	0,16	154,91
P.Degradada	0-10	5,89	3,89	66,11
	10-20	1,16	0,42	36,68
	20-40	0,29	0,16	55,82
	40-100	0,10	0,08	82,47
P.Mejorada	0-10	15,16	8,85	58,40
	10-20	3,75	1,61	42,90
	20-40	1,31	0,65	49,78
	40-100	0,29	0,26	89,42
Banco Mixto	0-10	3,11	3,13	100,64
	10-20	0,88	1,02	116,28
	20-40	0,39	0,38	98,16
	40-100	0,18	0,17	93,76
Bosque	0-10	6,37	8,26	129,70
Palo Alto	10-20	0,85	0,75	87,75
	20-40	0,30	0,22	73,40
	40-100	0,16	0,15	93,24
Bosque	0-10	4,48	6,32	141,25
San Antonio	10-20	1,05	1,40	132,76
	20-40	0,71	1,04	146,88
	40-100	0,09	0,16	184,81

Tabla 3. Producción de forraje en base seca en Kg/ha^{-1} de la asociación ***Brachiaria –A. pintoi*** y monocultivo de ***Brachiaria***

corte	sitio	fecha	Asociación			Monocultivo	
			Graminea	**Leguminosa**	**Maleza**	**Gramínea**	**Leguminoza**
1	EL DOVIO	05-Feb-04	1.621	198	52	2.177	58
2		31-Mar-04	462	98	19	780	32
3		27-May-04	477	147	42	1.132	46
4		22-Jul-04	1.670	125	54	1.558	113
5		16-Sep-04	1.225	147	78	2.678	91
6		11-Nov-04	589	183	108	1.061	190
1	DAGUA	09-Feb-04	1.784	562	139	1.626	60
2		05-Abr-04	788	538	80	868	58
3		31-May-04	908	305	50	866	65
4		26-Jul-04	1.129	326	80	1.224	90
5		20-Sep-04	893	156	182	1.171	88
6		16-Nov-04	657	292	106	383	66

Altura de corte gramínea a 20cm y leguminosa 5cm

3. Metología Cuantificación de Raíces Finas en Sistemas Estab. Dovio-Dagua

Para cuantificar las raíces finas se utilizó el suelo de los cilindros que fueron usados para determinar densidad aparente. El suelo seco de los cilindros fue saturado con agua durante dos días para facilitar la separación de las raíces, luego fue pasado por un tamiz fino y lavado varias veces para obtener las raíces limpias, una vez separadas, éstas fueron depositadas en papel servilleta y secadas al sol durante 24 horas; después se procedió a extraer elementos extraños como semillas, piedras y artrópodos pequeños, finalmente se tomó el peso en una balanza electrónica.

Tabla 4. Gramos de raíces (M.S) por kg de suelo en sistemas establecidos en el Dovio

Tratamiento	Profundidad cm	gr Raíces/kg suelo Media	D.E	C.V
P.Degradada	0-10	5,20	2,23	42,84
	10-20	2,00	0,61	30,62
	20-40	0,64	0,29	46,00
	40-100	0,37	0,35	96,10
P.Mejorada	0-10	5,20	2,59	49,87
	10-20	1,19	0,54	44,94
	20-40	0,44	0,18	41,02
	40-100	0,08	0,02	29,21
B.Mixto	0-10	11,37	19,68	173,05
	10-20	0,95	1,13	119,54
	20-40	0,54	0,89	164,40
	40-100	0,23	0,22	96,19
Bosque	0-10	7,07	4,82	68,18
	10-20	4,36	4,31	98,75
	20-40	1,47	1,53	104,46
	40-100	0,17	0,30	177,78

2. Producción de Forraje en las Parcelas Correspondientes a Bancos Mixtos

Una vez sembradas las parcelas y después de cortes 4 para el manejo mejorado y dos para el manejo local como cortes de estandarización se empezó a cuantificar la producción.
En las parcelas de árboles se determinó una parcela útil de 8 x 9 m y se cosechó en su totalidad, separando la producción por especie.

Tabla 1. Composición de la parcela útil de acuerdo al arreglo con las especies para el muestreo de árboles

Especie	Número de plantas	Composición por especie (%)	Área m^2	Composición por área en %
T. Diversifolia	62	61	28	39
T.gigantea	31	31	34	47
E. Poeppigiana	8	8	10	14
Total	101	100	72	100

Tabla 2. Producción de forraje en base seca por hectárea en el año 2004

Lugar	Manejo	Cortes	Producción Kg M.S/ha^{-1}	Intervalo Días	Precipitación mm/días
EL DOVIO	MEJORADO	1	2078.30	93	132
		2	511.65	56	268
		3*	2753.14	87	190
		4	444.17	66	277
	LOCAL	1	2075.39	93	132
		2	672.92	56	271
		3	2950.12	87	190
		4	496.71	67	277
DAGUA	MEJORADO	1	202.69	92	136
		2	191.59	56	209
		3	1408.93	91	232
		4	622.77	61	289
	LOCAL	1	221.45	87	136
		2	219.83	56	209
		3*	1606.07	91	232
		4	632.43	61	289

La ***T. diversifolia*** se cortó a una altura de 40 cm, ***T. gigantea*** a 1m o la altura que hubiera alcanzado y la ***E. poeppigiana*** a 1,5 o la altura que hubiera alcanzado.

Actividades en los Experimentos Establecidos en Áreas Degradadas en Laderas Andinas

Hernán Giraldo y María Elena Gómez

1. Datos parciales en Experimentos Establecidos en Áreas Degradadas

Establecimiento

Se utilizaron 3 Kg/ha de semilla de ***Braquiaria*** y 8 kg de ***Arachis*** sembrados a una distancia de 50 cm entre surco. La siembra correspondiente a los bancos mixtos se hizo en forma directa para ***Thitonia divesifolia*** con estacas 35-40 cm y con material producido en el vivero ***T. gigantea*** y ***Erythrina sp*** a partir de estacas y semilla respectivamente.

Fechas de Siembra

Sitio	Pastura	Árboles (Manejo Mejorado)	Árboles (Manejo Local)
El Dovio	Octubre 29/02	Noviembre 6/02	Junio 11/03
Dagua	Noviembre 31/02	Noviembre 7/02	Junio 18/03

Mantenimiento y Manejo

Las parcelas de árboles en la primera siembra corresponde a un manejo mejorado que incluye fertilización química y cobertura de ***Arachis pintoi*** . Otra repetición fue establecida 7 meses después y corresponde a un sistema local manejo que hacen los productores de la zona que consiste en fertilización orgánica (estiércol o lombricompuesto) que se genera dentro de las parcelas.

Fertilización

- **Manejo Mejorado**

Aplicación a la siembra 500 kg/ha $^{-1}$ calfos en Dagua y 300 kg/ha $^{-1}$ de fósforita huila en El Dovio y 100 kg/ha^{-1} de triple quince y 25 kg/ha^{-1} sulfato de Magnesio en ambos sitios.
De mantenimiento 50 kg/ha^{-1} sulfato de potasio y 100 kg/ha^{-1} de triple 15.

- **Manejo Local**

Fertilización a razón de 1 Kg/planta (15ton/ha^{-1}) de lombricompuesto en octubre 15/2004

Manejo Fitosanitario

- **Control de malezas** Se hace Manual y con guadaña en las calles.
- **Control de Atta sp** La hormiga arriera se presenta atacando el ***Arachis pintoi*** el manejo integral en forma manual interfiriendo las cámaras de los hormigueros, en el tiempo del vuelo nupcial, buscando las nuevas reinas y controlando manualmente.

Annex 7

Advancement Report June 1 – November 30, 2004
Anden Hillsides Sub-ecosystem, Colombia

5. Next Steps

- Continue with socioeconomic monitoring of farms;
- Disaggregate monitoring information according to production indexes of the different land use types,
- Start the design of preliminary models about the financial behavior of land uses with capacity to sequester carbon incorporating risk and uncertainty.

(iii) Annual budget for a calf (1-2 years) in a double-purpose production system

Concept		**Annual**	**Costo US$/unidad**	**Total anual (US$)**
1. Labor		2,2 jornales	6,97	15,28
2. Inputs				
Mineral Salt	Special Formula	10,7 kg	1,12	12,04
Common Salt	Granulated salt	21 kg	0,07	1,46
Vaccines	Brucelosis and tuberculosis	1 doses	1,88	1,89
Vaccines	Double: Septisemia (*Pasteurella multocida*) and symptomatic carbon (*Clostridium chauvoei*)	2 doses	0,33	0,67
Antiparasites	External (Ticks)	12 doses	0,14	1,00
Antiparasites	Internal (Ivermectina)	5,0 ml	0,47	4,77
Other medicines				2,09
			Total Final $	**39,20**

1 US$ = ¢ 430

(iv) Annual budget for a calf (2-3 years) in a double-purpose production system

Concept		**Annual**	**Costo US$/unidad**	**Total anual (US$)**
1. Labor		2,8 jornales	6,97	20,37
2. Inputs				
Mineral Salt	Special Formula	14,6 kg	1,12	16,35
Common Salt	Granulated salt	29 kg	0,07	2,04
Vaccines	Brucelosis and tuberculosis	1 dosis	1,88	1,89
Vaccines	Double: Septisemia (*Pasteurella multocida*) and symptomatic carbon (*Clostridium chauvoei*)	2 dosis	0,33	0,67
Antiparasites	External (Ticks)	12 dosis	0,112	1,34
Antiparasites	Internal (Ivermectina)	5,0 ml	0,47	6,674
Other medicines				2,79
			Total Final $	**52,12**

1 US$ = ¢ 430

4.3. Annual Maintenance Costs of Different Categories of Animals

Following are the maintenance costs for the different types of animals (cow, heifer, calf) that form the typical double-purpose herd in the farms of the project[2].

(i) Annual budget for a cow in a double-purpose production system

Concept		Annual units	Cost US$/unit	Total annual (US$)
1. Labor		3,6 jornales	6,97	25,46
2. Inputs				
Mineral Salt	Special Formula	18,2 kg	1,12	20,44
Common Salt	Granulated salt	36,5 kg	0,07	2,50
Gallinaza		13,6 bags	0,86	11,81
Melaza (miel)		7,9 liters	0,18	1,48
Vaccines	Brucelosis and tuberculosis	1 doses	1,88	1,89
Vaccines	Double: Septisemia (*Pasteurella multocida*) and symptomatic carbon (*Clostridium chauvoei*)	2 doses	0,33	0,67
Antiparasites	External (Ticks)	12 doses	0,14	1,67
Antiparasites	Internal (Ivermectina)	8,0 ml	0,47	7,62
Other medicines				3,49
			Total Final $	77,08

1 US$ = ¢ 430

(ii) Annual budget for a heifer in a double-purpose production system

Concept		Annual units	Cost US$/unit	Total annual (US$)
1. Labor		1 jornal	6,70	6,70
2. Inputs				
Mineral Salt	Special Formula	4,8 kg	1,12	5,37
Common Salt	Granulated salt	9,9 kg	0,07	0,69
Vaccines	Double: Septisemia (*Pasteurella multocida*) and symptomatic carbon (*Clostridium chauvoei*)	3 doses	0,33	1,00
Antiparasites	External (Ticks)	12 doses	0,05	0,67
Antiparasites	Internal (Ivermectina)	2,0 ml	0,47	2,86
Other medicines				4,65
			Total Final $	21,94

1 US$ = ¢ 430

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[2] For a complete description of the characteristics of the farms, their cattle production systems and herd structure, refer to the document "Caracterización socio-económica de las fincas del proyecto en la Región Pacífico Central de Costa Rica". Internal Document No. 9, December, 2003.

4.2. Annual Maintenance Costs of Different Types of Pastures

(i) Degraded pasture

The next table shows the annual maintenance costs of one hectare of degraded pasture.

Concept	Units	Cost US$/unit	Total (US$)
1. Labor			
Weed control	1 jornal	6,98	6,98
Herbicide application	1 jornal	6,98	6,98
		Subtotal	13,96
2. Inputs			
Herbicide	1 liter	10,02	10,02
		Total Final $	23,98

1 US$ = ¢ 430

(ii) Natural pasture

Natural pastures are dominated by grasses that are susceptible to drought and light exposition (*Hyparrenia rufa, Paspalum* sp), so allowing natural regeneration of trees and weeds. This situation implies that a significant amount of labor and herbicide is required for their management. Next, costs of annual maintenance of one hectare of natural pastures are shown.

Concept	Units	Cost US$/unit	Total (US$)
1. Labor			
Weed control	8 jornales	6,98	41,88
Herbicide application	2 jornales	6,98	13,96
		Subtotal	55,84
2. Inputs			
Herbicide	3 liters	10,02	30,06
		Total Final $	85,90

1 US$ = ¢ 430

(iii) Improved pasture

Once established and under proper management, the maintenance costs of an improved pasture are lower than those of a natural pasture. The annual maintenance costs of one hectare improved pasture are presented in the next table.

Concept	Units	Cost US$/unit	Total (US$)
1. Labor			
Herbicide application	1 jornal	6,98	6,98
2. Inputs			
Herbicide	1 litro	10,02	10,02
		Total Final $	17,00

1 US$ = ¢ 430

4. Results

4.1. Establishment Costs

The establishment costs of improved pastures and fodder banks in the sub-humid tropical forest zone of Costa Rica are detailed in the following tables. Costs are expressed per hectare in US dollars.

(i) *Brachiaria* spp improved pasture

Concept	Units	Cost US$/unit	Total (US$)
1. Soil preparation			
Application of herbicide 1Glifosato	4 lt	4,63	18,52
Application of herbicide 2 Xeraxone	3 lt	5,58	16,74
Gasoline	1,5 gallons	2,55	3.83
		Subtotal	39,09
2. Sowing and management			
Seed purchasing	3 pots	18,07	54,21
Seed treatment Vitaba	1 bags	3,10	3,10
Weed control 2-4 D	2 lt	3,43	6,86
Fertilization 12-24-12	1 quintal	12,12	12,12
		Subtotal	76,29
3. Labor			
Soil preparation	4 jornales	7,23	28,92
Sowing and management	6 jornales	12,05	72,30
		Subtotal	101,22
		Total $	**216,60**

1 US$ = ¢ 425

(ii) *Cratylia* fodder bank

Concept	Units	Cost US$/unit	Total (US$)
1. Inputs			
Herbicides	2 gallons		96,36
Cratylia Seeds	5 kg		156,64
Fertilizer 10-30-10	13 quintals		125,30
Seed transport	1 freight charge		4,82
		SubTotal	383,13
2. Labor			
Herbicide application	3 jornales		26,69
Ploughing with bullocks	9 pie de buey		65,06
Sowing	10 jornales		72,29
Fertilization	4 jornales		28,92
Weed control	3 jornales		21,69
		Subtotal	209,64
		Total Final $	592,77

1 US$ = ¢ 425

Advances in the Socioeconomic Component
June 1- November 30, 2004

J. Gobbi, F. Casasola and J. Chagoya

1. Introduction

The "Research Network for the Evaluation of Carbon Sequestration Capacity of Pasture, Agropastoral and Silvopastoral Systems in the American Tropical Forest Ecosystem" Project has as its main goals to contribute to sustainable development, to reduce poverty and to mitigate the undesirable effects of climate change — particularly CO_2 emissions— in the most vulnerable forest sub-ecosystems of Tropical America. With this purpose, the socioeconomic component of the Project is addressed to evaluate the economic and financial attractiveness of the Pastoral, Agropastoral and Silvopastoral Systems (PASPS) with the capacity to sequester carbon, and compare them with the conventional livestock systems developed on degraded pastures. The information generated from the socioeconomic analysis will be used as an input for the later formulation of political guidelines for the payment of incentives derived from carbon sequestration in these tropical land use systems. During the second semester of 2004 the socioeconomic monitoring was accomplished in the farms of the Costa Rican semi-humid tropical forest region. In this report we present a summary of what was accomplished in this socioeconomic monitoring.

2. Objectives of the Socioeconomic Component

- Determine the structure of investment costs and management of the PASPS with capacity to sequester carbon, as well as their production levels;
- Determine the financial profitability of the PASPS with capacity to sequester carbon in comparison with the conventional livestock systems developed on degraded pastures;
- Develop models about the effects of the payment of an incentive for the adoption of PASPS with capacity to sequester carbon; and
- Provide political guidelines for the payment of incentives for carbon sequestration to farmers in the American tropical ecosystems.

3. Implemented Activities

The activities carried out during the second semester of 2004 were the following[1]:

- Continuation of farm monitoring by means of activities and production records
- Estimation of the establishment costs of improved pastures and fodder bank
- Monitoring of the maintenance costs of degraded, natural, and improved pastures
- Estimation of the maintenance costs of the different animal categories

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[1] For a detailed description of the socioeconomic component methodology, see the document "Aspectos metodológicos de la evaluación socio-económica de sistemas silvopastoriles, agro-silvopastoriles y silvo-pastoriles con capacidad para el secuestro de carbono". Internal document No. 9, December, 2003.

Advances in the Biophysical Component
June 1 – November 30, 2004

Muhammad Ibrahim and Tangaxuhan Llanderal

1. Introduction

The biophysical component of the Project focused on the evaluation of biomass availability and soil analyses of the different land use systems that are under evaluation in two regions. Selected land-use systems are being sampled in both the Atlantic (Pocora) and the Pacific (Esparza) Coasts of Costa Rica, and an experiment was set up in the Pacific Coast Region. The purpose of this evaluation is to compare the biomass productivity and the characteristics of the soil, mainly those related to carbon storage, between the different land-use systems under study. This information will be used to propose land-use change practices that contribute to store carbon in soils and vegetation. Here we present a summary of the activities that were accomplished during the second semester of 2004.

2. Implemented Activities

Activities during this period were mainly related to biomass availability samplings in both the selected sites in Esparza and Pocora and the new experiment established in Esparza. This sampling has not yet finished.

Besides this, the Ph.D. student Tangaxuhan Llanderal is conducting a study in the Atlantic Zone of Costa Rica with the objective of determining the effects of substituting pastures by forests on the soil carbon storage. Paired sites have been selected and soil samples are being taken for physical and chemical analyses. The results of this study will be of substantial importance to the achievement of the Project objectives.

3. Next Steps

During the next semester, the following activities will be carried out:

- Continue the samplings of biomass availability.
- Soil sampling in the selected sites in Esparza and Pocora, and in the new experiment. Soil pitches are currently being excavated and sampling will be finished during the next two months.
- Start statistical analysis of the new data

Annex 6

Advancement Report June 1 – November 30, 2004, Sub-humid and Humid Tropical Forest Sub-ecosystem, Costa Rica

Table 9. Gross margin (GM) obtained from different production lines in the farms during July to September of 2004 (Data in US$). Gross margin obtained by hectare is also showed.

Sample	Cattle	Rubber	Fruits	Chickens	Pigs	Others	Gm Farm	$Gm.Ha^{-1}$
Farm1	-209.17	536.20	-2.96	21.11		413.89	760.55	9.05
Farm2	385.77			64.81		71.85	522.43	7.92
Farm3	-948.26	1014.97	1.85			85.93	154.48	0.77
Farm4	-696.82		8.52		192.59	50.74	-444.96	-7.29
Farm5	-255.22					273.70	22.18	5.55
Farm6	-231.13	66.91	7.96			614.28	458.02	14.77
Farm7	-41.86	460.84					434.54	25.56
Farm8	-370.67		2.22	14.81		131.48	-222.15	-3.22

Despite just two farms obtained negative gross margins, it is necessary to remind that all data showed in Table 9 are just representative of a three months period, a quarter part of the minimum suggested to conclude the study (one year).

New Activities

These results must be completed which obtained from the other three quarter periods. There are necessary nine workshops to collect information that will be monthly transferred to the data base and the final conclusion could be obtained after this.

Table 8. Total paid (in US$) for supplies of the different activities in the sampled farms, during July to September of 2004.

SAMPLE	CATTLE	DEGRADED PASTURE	IMPROVED PASTURE	FORAGE BANK	GARDEN PATCH	RUBBER
Farm1	72.85	8.53	8.53	9.48	9.26	9.26
Farm2	217.85	64.70	64.70	7.74		
Farm3	202.07	53.10	53.10	38.14	7.41	34.07
Farm4	20.37	162.27	162.27	150.06		
Farm5	2.96	17.72	17.72	17.72		
Farm6	17.93	2.12	2.12	0.49		15.37
Farm7	49.81	2.78	2.78	1.85		2.59
Farm8	72.44	21.85	21.85	25.67		

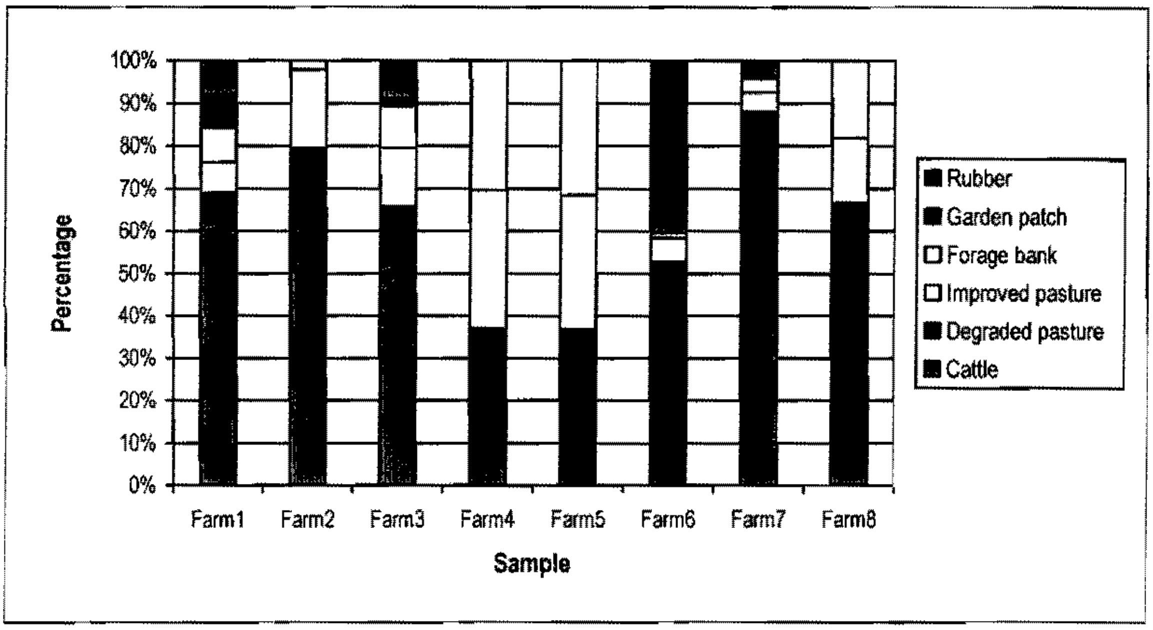

Figure 3. Contribution (as percentage) of the different activities to the total paid.

From difference between gross production and total paid for materials or supplies to the activities in the farms, the gross margin is obtained (Table 9). As expected, losses caused by cattle activities were softly diminished by milk production incomes, and rubber, fruits, chickens, pigs and others sales let exchange the total gross margin into the positive values.

Table 7. Gross production (GP) obtained from different production lines in the farms during July to September of 2004 (Data in US$).

Sample	Cattle	Rubber	Fruits	Chickens	Pigs	Others	Gp
Farm1	368.03	545.46	6.30	21.11		413.89	1356.27
Farm2	1288.91			64.81		71.85	1425.58
Farm3		1049.04	9.26			85.93	1144.23
Farm4			8.52		192.59	50.74	251.85
Farm5						273.70	277.41
Farm6	90.61	82.28	7.96			614.28	795.13
Farm7	394.10	463.44					873.10
Farm8	136.89		2.22	14.81		131.48	285.41

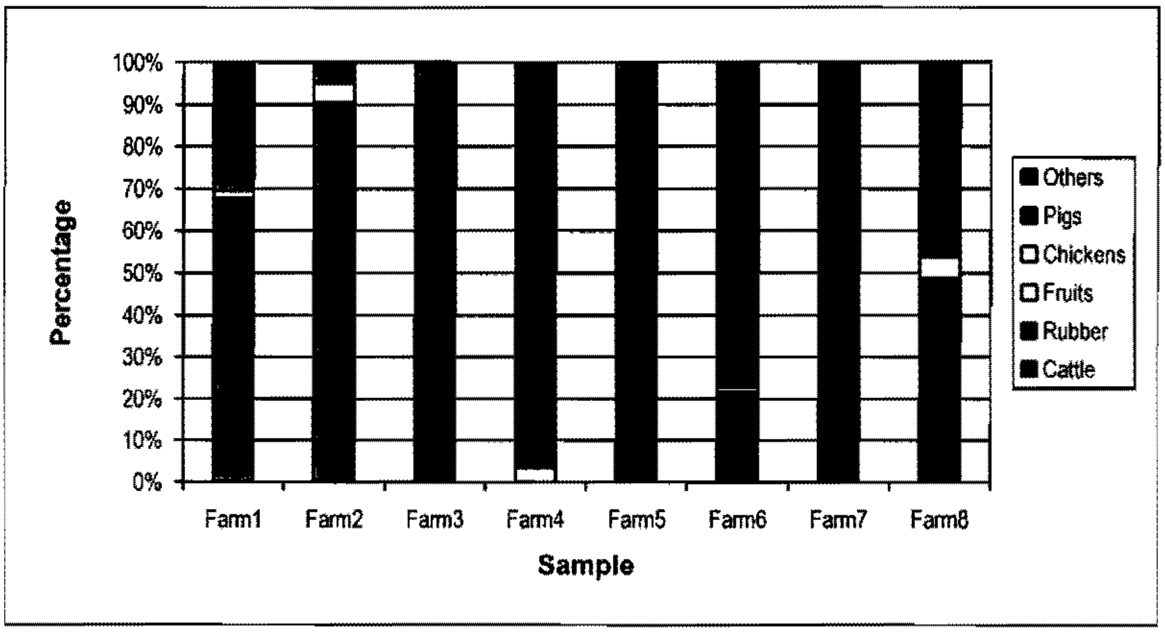

Figure 2. Contribution of the different activities to the gross production obtained during July to September of 2004 in the sampled farms.

The same behavior of the total paid for supplies to the different activities in the farm was expected. But, there were not much paid for materials to the rubber processing (Table 8 and Figure 3). The main costs were likely paid during vegetative period of the *Hevea brasiliensis*, and after beginning the production few maintenance activities are necessary to continue the rubber production.

Table 6. Costs (US$) of the familiar workmanship (FW), distributed by the activities in the farms, since July to September of 2004. Paid temporal workmanship (TW) is also showed.

Sample	Cattle	Degraded Pasture	Improved Pasture	Forage Bank	Garden Patch	Rubber	Total Fw	Tw
Farm1	477.78	29.63		55.56	114.81	333.33	1011.11	85.19
Farm2	548.15	222.22	259.26	7.41			1037.04	503.70
Farm3	602.22	259.26		7.41	103.70	259.26	1231.85	600.00
Farm4	202.22	0.93	0.93	57.41	100.00		361.48	
Farm5	199.26			62.96	59.26		321.48	
Farm6	299.26	29.63	22.22	25.93	137.04	185.19	699.26	37.04
Farm7	378.52	11.11	25.93	48.15	63.89	225.93	753.52	81.48
Farm8	365.93	61.11	98.15	44.44	91.85		661.48	74.07

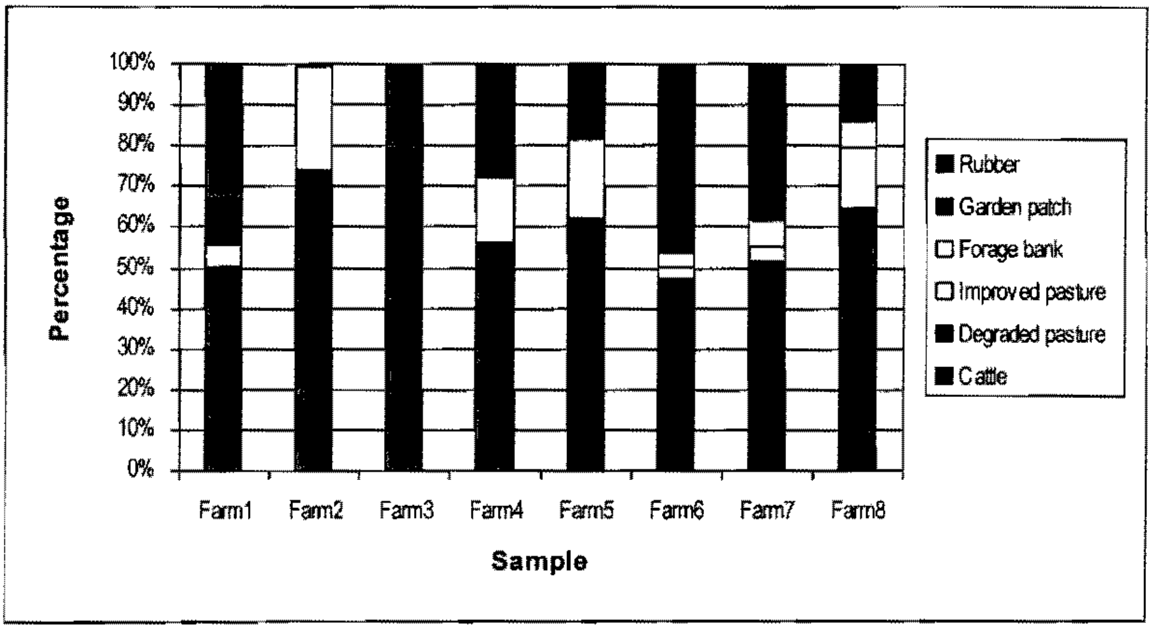

Figure 1. Workmanship used in the sampled farms as percentage of total activities.

Rubber is the second higher contribution to the gross production of the sampled farms, followed for pig production. However, self-consumption is very important too, and is represented in the "Others" column in Table 7. Several of the farms produce eggs, wood, vegetables like banana, tomato, onion, and so, for sale or to be consumed by the farmer's family.

Table 5. Activities developed in the farms. Each number reflects the quantity of farms where the activity was made.

Activity	Degraded Pasture	Improved Pasture	Forage Bank	Garden Patch	Afs* Rubber
Cleaning	5	3	8	4	4
Fertilization			5	6	1
Herbicide application	3	3			
Re-sowing		2		5	1
Fruit collect				6	
Cut and carry			8		
Rubber processing					4

*: Agroforestal system

Variation on milk production could be explained by both cross-breeding effect and different milking intensities. In addition, a rainy climatic condition has a notorious effect on it; the stronger the rainy weather the lower the milk production. Wet soils and pastures are more affected by cattle footing.

Opposite to data obtained during the proof test (June), different activities were developed in the pastures (Table 5), likely for weather change. There were several sunny days during the studied period.

As shown in Table 6 and Figure 1, most of the workmanship used by the farmers is the familiar sort, mainly occupied for cattle activities (milking, supplementation with salt, bath, etc.), but several times is necessary the use of temporal workmanship .

Where *Hevea brasiliensis* was established, rubber processing is likely the second more important activity that demands the available workmanship. If it is not present at the farm, the workmanship is shared with different activities like cut and carries from the forage bank and garden patch or pastures maintenance.

Table 7 shows the gross production of the farms. As expected, cattle (including milk production) represent the main contribution to the gross production. The milk is paid about 0.16 – 0.17 US$.$l^{-1}$ for a multinational company (Nestlé) to condense and transport to their factories. But there are people too, who paid for the milk to commercialize it with the inhabitants of the nearest towns or cities.

Farm size doesn't necessarily reflect quantity of animals (Table 3). It is explained for the improved pasture areas, because is not recommendable to have in the farm more animals than can be feed.

Most of animals are female (Table 4), due to the dual purpose cattle productive model, where continuous incomes are expected from milk production. The stocking rate ranges between 0.5 and 1.6 animals.ha^{-1} with average of 1.05 animals.ha^{-1}.

Table 3. Cattle productive indicators updated to September of 2004.

Indicator	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	**Farm 5**	**Farm 6**	**Farm 7**	**Farm 8**
Total animals	111	67	90	40	5	39	28	48
Stocking rate (animals.ha^{-1})	1.3	1.0	0.5	0.7	1.3	1.3	1.6	0.7
Milk production (l.vaca^{-1}.dia^{-1})	1.8	3.5	2.0	2.2	3.3	1.4	1.7	1.4

Table 4. Cattle inventory in the sampled farms. Data updated to September of 2004.

	Farm1	**Farm2**	**Farm3**	**Farm4**	**Farm5**	**Farm6**	**Farm7**	**Farm8**
Females								
Calfs < 1 year	16	17	10	4		4	7	4
Heifers 1 – 2 years	15	12	5	15			2	
Heifers 2 – 3 years	17	3	10			8	1	6
Cows for replacement	1		8					
Calved cows without milking	8		5		3	2	3	5
Milking cows	14	20	24	3	1	4	7	7
Dry cows	19	8	9			7	2	8
Total females	**90**	**60**	**71**	**22**	**4**	**25**	**22**	**30**
Males								
Calfs < 1 year	12	4	14	4	1	5	4	2
Steer 1-2 years	4			5				6
Steer 2-3 years				6		4		4
Steer > 3 years								
Breeding	2	1	2	1		1	1	2
Total males	**18**	**5**	**16**	**16**	**1**	**10**	**5**	**14**
Horses and mules	3	2	3	2		4	1	4
TOTAL ANIMALS	**111**	**67**	**90**	**40**	**5**	**39**	**28**	**48**

Results

All the sampled farms are located about 24 km from the nearest town or city, on mild-slope topography within the Amazonian hills and/or hillocks relief (known as "lomerío").

The farm size is varying between 4 and 200 ha with 66.5 ha as average (Table 2). About 74% of their areas are dedicated to pasture. This fact lets deduce cattle as the main productive activity in them. However, averages of degraded and improved pasture areas are 32.5 ha and 41.6 ha, respectively, correspondingly to 43.8% and 56.2% of the total pastures. For using as food supplement, a forage bank of about 0.125 ha was established by the farmers.

As regional mean, 88% of the sampled farmers are living in the farmhouses, 77% of them masonry built, with more than six rooms in several cases. Almost all the farms are covered by electric energy. Despite this, 18% of the houses have not yet any kind of public service.

In average, each family is composed by 4.6 people. Respect to gender, male presence is higher than female with 62.2% and 38.8%, respectively. It differs the regional mean where male is just low higher than female, with a difference lesser than 5%.

Families are formed by young people. Age ranges between 11 and 49 years old for about 75% of the people. On the schooling hand, females average 5 school years whilst male mean is around 7.

Table 2. Main characteristics of the farms sampled for developing this study.

Sample	Farm Area (Ha)	Relief	Degraded Pasture (Ha)	Improved Pasture (Ha)	Forage Bank (Ha)	Inhabitants (N°)	Men	Women
Farm1	84	Mild-slope Hills / hillocks	30	20	0.125	3	2	1
Farm2	66	Mild-slope Hills / hillocks	15	40	0.125	5	3	2
Farm3	200	Mild-slope Hills / hillocks	140	35	0.125	3	2	1
Farm4	61	Mild-slope Hills / hillocks	35	20	0.125	7	5	2
Farm5	4	Mild-slope Hills / hillocks	1.5	2	0.125	5	3	2
Farm6	31	Mild-slope Hills / hillocks	5	21	0.125	7	4	3
Farm7	17	Mild-slope Hills / hillocks	1	10	0.125	4	2	2
Farm8	69	Mild-slope Hills / hillocks	10	15	0.125	3	2	1

Socio-economic Report
Results of Farm Production Indices

Bertha Leonor Ramírez y Jader Muñoz-Ramos

Introduction

To contribute to develop the second objective of the proposal final version, electronic registers and data base were designed, using electronic sheet format software, in order to perform an economic assessment of the production systems of some of the farmers at the Colombian Amazonia.

As shown in Table 1, a physical register was depicted to the farmers through participative methodology. All their doubts about how to fill out the formats were answered within a workshop.

Table 1. Developed activities to collect basic data to perform an economic assessment of the farmers' production systems established on the influence area of the project.

Activity	Date
Initial activities coordination meeting	September – 2003
Electronic register and data base designs	May – 2004
Workshop with farmers • To describe registers to the farmers • To choose farmers for proof testing	June – 2004
Transfer registers information into the data base	July – 2004
Register and data base adjusting	July – 2004
Monthly workshops to collect farmer information	July to September – 2004
Transfer registers information into the data base	October – 2004
Monthly workshops to collect farmer information	October to November – 2004

Thereafter, five of them were elected for carrying out a proof testing on June of 2004; a book with a physical register was given to each one. The collected information lets to adjust the registers and data base on July of 2004.

From July of 2004, the sampling was extended until 8 farmers who have being filling out physical registers and given the information to the project in workshops prepared monthly for it. Besides the job, the workshops have also been being a time share for constructing social web between them.

As data base was designed for processing information 4 times a year (inputs must be in periods of three months) and an appropriate economic assessment should be run for data collected for at least a year, here is an advance of the results obtained from July to September of 2004, using a money exchange of 1 US$ = $2700.oo as basis for calculations.

Table 3. Comparison of the mean dry matter produced in plots of *Brachiaria* alone or associated with *Arachis pintoi* in two types of soils (Sloped = Balkanes; Flat = Santo Domingo) in the amazonian piedmont

Component	**Brachiaria**		**Brachiaria + Arachis**	
	Balkanes	**Santo Domingo**	**Balkanes**	**Santo Domingo**
Main Grass	3284.2	1947.4	2896.4	1864.4
Other Grasses	191.6	53.4	171.8	165
Legume	4.2	30.2	1121.2	581.2
Weeds	153.8	8.6	28.8	16.4
Total DM	3633.8	2039.6	4218.2	2627

In Table 4, the botanical composition indicate no differences for the main grass or the legume in the two topographies. However, there is a higher presence of bare soil in the Brachiaria alone (more than 35%) than in the association (less than 10%) or in the regeneration plots (0%).

The natural regeneration plots exhibit a greater presence of weeds (more than 23%) than the planted plots (less than 8%). Weeds consisted mainly of *Imperata* sp.

Table 4. Comparison of the mean botanical composition in paddocks of natural regeneration, *Brachiaria* alone or associated with *Arachis pintoi* in two topographies (Slope = Balkanes; Flat = Santo Domingo) in the amazonian piedmont

Component	**Natural Regeneration**		**Brachiaria**		**Brachiaria + Arachis**	
	Balkanes	**Santo Domingo**	**Balkanes**	**Santo Domingo**	**Balkanes**	**Santo Domingo**
Main Grass	42.56	68.22	51.03	51.65	47.69	44.9
Other Grasses	5	3.08	5.37	3.09	3.3	4.8
Legume	1.36	5.25	0.34	1.38	40.06	38.43
Weeds	51.08	23.45	8.18	0.45	2.15	1.12
Bare Soil	0	0	35.08	43.43	6.8	10.75

Future Activities

To date, there is one sampling remaining for 2004 in Santo Domingo, as it was programmed for December 16. It is expected to continue the evaluation during 2005-2006 in order to see the persistence of the species. For 2006, sampling of the soils are expected to be done in order to determine the amount of carbon present.

Francisco Casasola presented plans for the estimation of **Vegetation-C in Agroforestry systems** by determining the biomass of the fractions of woody species and analyzing these for Carbon content.

Dr. 't Mannetje pointed out that the C concentration of many plants tend to be very similar and he suggested that Mr. Casasola should first do a literature review on carbon content of different species. If this would be with a 5% range of a mean than only biomass determination would be necessary, thus saving money on C analysis.

2. Present Status of New Proposals.

M.C. Amezquita discussed ideas for new activities:

a. Greenhouse Gas Fluxes by a group of scientists from Gent, Belgium. They are prepared to give a course on this subject. However, it was considered that work on fluxes would not add to the objective of our project. Other greenhouse gases than carbon (Methane, Nitrate oxide) are outside the scope of our project.
b. UNITROPICO would be willing to work on carbon stocks in savannas in Colombia, but it was agreed that savannas are outside the scope of our project.
c. Dr. M.C. Amezquita, Dr. E. Amezquita and Dr. M.A. Ibrahim have discussed a proposal to invite 5 world renowned scientists to present their views on Carbon sequestration after the next International Coordination Meeting to a large fee-paying audience from within Latin America. However, it was pointed out that his would be like an international meeting with all the consequences of organizing such a meeting and its financial liability. Who would be responsible for the financial loss that might occur?

The next International Coordination Meeting will be held at CIAT, Colombia in the first week of September 2005 (August 29 –September 2, 2005).

V International Coordination Meeting
Punta Leona, July 26-29, 2004

Summary of Discussions and Recommendations
Session of Thursday 29 July

Discussion Moderator: **L. 't Mannetje**

Session **FUTURE ACTIVITIES-ANNUAL PLAN FOR 2005**
Discussion Moderator: **L. 't Mannetje**

1. Mathematical Modeling by Dr. Bram van Putten

Dr. Van Putten outlined new approaches to simulation modeling of carbon sequestration based on mathematical and statistical modeling. The ingredients necessary for this are *knowledge* and *databases*. The results will increase qualitative insight, identify gaps in knowledge and will allow answering *What if?* questions. Models should be simple and should not be used for extrapolation too far beyond prevailing experimental conditions. The objectives would be:

a. to identify sub-ecosystems with high capacity for carbon sequestration.
b. to develop a model to extrapolate within TLA Forest Ecosystems
c. to predict C-stocks and changes as functions of climate, topography, soil, etc. to places unvisited.

Existing models have been developed and calibrated only for temperate climate areas. Rates of change in the tropics are much faster than in temperate zones. Existing models have no confidence limits. Models are black boxes.

Statistical models may offer a solution. For this whole plots must be considered as experimental units. However, the present database does not have enough plots. C-stocks must be integrated over whole plots.

Preliminary calculations indicate that statistical models function much better than process-based models.

Chromo sequence modeling is used to look at the present to explain the past. This appears very promising for our data.

It was agreed that the modeling work of Van Putten should receive priority in more investment, because the project must result in a useful model for extrapolation.

3) Other measurements:

The group discussed of the importance for collecting data on root biomass which could be important to explain the data on carbon stocks and sequestration. The group agreed that the project should invest some funds for the measurements of root biomass. M. Ibrahim explained that CATIE had been working on several projects for quantification of root biomass in collaboration with GTZ and University of Gottingen and agreed to send the methodology used for root measurements to the group. Edgar Amezquita will use this methodology to discuss with the CIAT group to make modifications if necessary

4) General Comments:

M. Ibrahim explained that the project should make a clear distinction of what is degraded pastures as in most of the sites the degraded pastures are characterized with a high percentage of weeds but with a large amount of standing biomass which contributes to C- sequestration and this is one of the reasons for not finding large differences between the treatments and degraded pastures. The hypothesis that the set out to test was that there was a gradient in carbon stocks such that degraded pastures had the lowest amount and that this increased with improved pastures, fodder banks, improved pastures and legumes, silvopastoral systems (grass and trees) and secondary vegetation. It was agreed that in all sites the project should try to identify areas with soil degradation and do some sampling.

V International Coordination Meeting
Punta Leona, July 26-29, 2004

Summary of Discussions and Recommendations
Session of Tuesday 27 July, pm

Discussion Moderator: ***Muhammad Ibrahim***

1) Evaluation of small plot experiments- all sub-ecosystems:

a) the data on soil characterisation and standing biomass of the pasture treatments of the Costa Rican site in Esparza was presented by Tanguzan. In this presentation Edgar Amezquita observed that there may be some errors of the calculations on total carbon which may be associated to the use of decimals. The Costa Rican group agreed to review the data and make changes where necessary. This experiment will continue for another 1.5 yrs.

b) Data on biomass and soil for evaluation of small plot experiments for the Andean Hillside was presented by ME Gomez and H. Giraldo. The data showed that biomass production of grass-legume treatment was higher than other treatments tested. The biomass of fodder banks was lower than that compared to the other treatments. Fodder banks generally take a longer time to meet peak production and given that the duration of the experiment is about 3 yrs, the grass treatment may have an advantage given that grasses can achieve peak production much earlier after establishment. Enrique proposed a change in the management of the improved fodder to reduce exportation of nutrients and to enhance C sequestration. This involves the use of material pruned from poro trees as mulch in the system, This proposal was accepted by the group

c) Evaluation of small plot experiment- Amazonia: The data on soils and biomass of this area was presented by B. Ramirez and H. Giraldo. Some differences were observed in the trends of production

As a general comment the group agreed to extend the time for taking measurements in the newly established experiment with an understanding that all measurements should be completed by the first trimester in 2006 which will allow for data analysis and reporting.

2) Worm evaluation and preliminary sampling data:

L Gomez and H. Giraldo presented data on earthworm biomass and density in some treatments of the Andean ecosystem. Earthworm population and biomass was generally higher for the natural regeneration site and improved pasture but there was not a good relationship between earthworm data and total and oxidisable carbon. Peter Buurman mentioned that information on earthworm population is a good indicator of soil quality and edible litter but there were not clear relationships between earthoworm and C stocks. Based on these arguments the group agreed that it was not necessary to invest more resources for measurements of earthworm.

V International Coordination Meeting
Punta Leona, July 26-29, 2004

Summary of Discussions and Recommendations
Session of Tuesday 27 July, am

Discussion Moderator: ***E. Amezquita***

Humid Tropical Forest, Amazonia, Colombia

Three aspects were presented and discussed:

1. Soil Carbon Stocks in long term systems and statistical analysis
2. Socio-economical evaluation
3. General recommendations .

The following recommendations were drawn:

1. *In relevation to Soil Carbon Stocks*

a. It's needed to revise the Laboratory methodology for C-determinations. E. Amezquita, will ask Octavio Mosquera to send the protocol to Peter Buurman.
b. It's advisible to send some samples to Wageningen for checking
c. It's advisible to repeat analysis, in all places to be secured of accuracy of results.

2. *Socio-economical analysis:*

Should be complemented with an analysis of potential land use, for a more productive use.

V International Coordination Meeting
Punta Leona, July 26-29, 2004

Summary of Discussion and Recommendations
Session of Monday 26 July, pm

Discussion Moderator: ***P. Buurman***

1. Calculation of Carbon Stocks.

Notwithstanding different current practices in many parts of the world and even by renowned scientists, the project should present its data and comparisons on a basis of fixed mass.

2. Protocol on publications

Because all data are owned by the project and are to be shared by many scientists there should be a clear protocol about publications and authorship. It was proposed that prospective authors send possible titles to the project director. The project director, on the other hand, should inform all participants of papers that are to be written. This way, prospective (co-) authors can make themselves known and we can make sure that participants are not sidetracked.

There is a clear preference among the participants of the meeting that younger project members should be first authors wherever possible. This may be different between scientific papers and policy papers.

3. Multivariate analysis

Multivariate analysis can be carried out on separate areas. Areas can only be combined for multivariate analysis when the mass basis of the calculations is equal.

4. In-field variations.

In the present presentations of carbon stock comparisons, the figures for the different positions in the fields have been lumped. It would be better to take the position of the samples in the field (slope position) as an additional variable. Additionally, comparing field by slope position may give better results than comparing means of fields (treatments), especially when slope trends do exist

5. Soil classification

For extrapolation of data and international understanding, the investigated soils in each area should be classified according to USDA. The local groups are requested to do this.

V International Coordination Meeting
Punta Leona, July 26-29, 2004

Summary of Discussions and Recommendations
Session of Monday 26 July, am

Discussion Moderator: **L. 't Mannetje**

1. Session: Overall project advances

a. M.C. Amezquita presented an overview of project progress over the period Sept 2003 till July 2004

The discussion dealt with definitions of soil carbon fractions, which were explained by P. Buurman.

b. J. Gobbi reported advances in socio-economic research between Sept 2003 and July 2004. *It was agreed that ecosystem improvement to enhance Carbon sequestration must be economically sustainable.*

2. Session: Humid and sub-humid Tropical Forest, Costa Rica

a. T. Llanderal presented data and results of statistical and principal component analyses on soil-C and Vegetation-C.

There were few statistically significant differences in SCS between different ecosystems.

It was agreed that it would be better to apply principal component analyses to individual ecosystems than to the collective database of all ecosystems, because the latter would contain too many data that are not directly related to carbon sequestration and result in clusters of sites that are not necessarily explanatory for levels of carbon sequestration.

b. J. Gobbi discussed the evaluation of socio-economic data.

The data were mainly related to costs and returns of farm productivity, including capital costs.

Thursday July 29

Moderators: Prof. L. 't Mannetje (morning session)

Future Activities - Annual Plan 2005		
8:00 - 9:00am	Mathematical modelling in the Project. Options.	Bram van Putten
9:00 - 9:30am	Discussion, Recommendations and Agreements	
9:30 - 10:00am	Vegetation–C in AF systems: Methodology and Costs. Costa Rica systems only?	M. Ibrahim
10:00 - 10:15am	Recommendations and Agreements	
10:15 - 10:30am	Coffee	
10:30 - 10:45am	Intellectual property of Project's data. Centralised Project Database: Bio-physical and Socio-economic data on the three Sub-ecosystems	L. 't Mannetje
10:45 - 11:00am	(1) Present State of New Proposals; (2) Date and Place – VI Int. Coordination Meeting; (3) Date of CIAT's workshop for SCS data analysis	M.C.Amézquita
11:00 - 11:15m	Agreements	
General Recommendations and Agreements – Closing Session		
11:15 - 12:15pm	"Recommendations and Agreements". From session moderators. (Please handle an electronic version with Summary Recommendations to Francisco Ruiz)	All Session Moderators
12:15 - 12:30pm	Hotel Check-out	
12:30 - 2:30pm	Lunch	
3:00pm	Departure to San Jose	

- Moderators of discussion sessions are asked to prepare a summary report in magnetic media to be presented at the Closing Session and handled to F. Ruiz.

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Tuesday July 27

Moderators: E. Amézquita (morning session) and M. Ibrahim (afternoon session)

Humid Tropical Forest, Amazonia, Colombia		
9:00 - 10:30am	SCS Evaluation in Long-established Systems and Statistical Analysis.	M.C.Amézquita, H.F. Ramírez and H. Giraldo
10:30 -10:45am	Discussion and Recommendations	
10:45 -11:00am	Coffee	
11:00 -11:30am	Socio-economic Evaluation	B.Ramírez and J. Muñoz
11:30 -12:00m	Discussion	
12:00 -12:30pm	General Recommendations SCS and Socio-economic evaluation – Amazonia. 2nd Lab. Results.	
12:30 - 2:30pm	Lunch	
Evaluation of Small-plot Experiments – three Sub-ecosystems		
2:30 - 3:00pm	Evaluation of Small-plot Experiment – Costa Rica	M.Ibrahim, T. Llanderal and A. Navas
3:00 - 3:15pm	Discussion	
3:15 - 3:45pm	Evaluation of Small-plot Experiments – Andean Hillsides	M.E.Gómez and H. Giraldo
3:45 - 4:00pm	Discussion	
4:00 - 4:15pm	Coffee	
4:15 - 4:45pm	Evaluation of Small-plot Experiments – Amazonia	B. Ramírez, H. Giraldo
Worms Evaluation – A proposal		
4:45 - 5:15pm	Worms Evaluation Methods and preliminary sampling data	L. Gómez, H. Giraldo
5:15 - 5:30pm	Discussion	
5:30 - 6:00pm	General Discussion: Small-plot Experiments and Worms evaluation. • 3rd C-sampling on small plot experiments? • Continue or not with worms evaluation?	

- Moderators of discussion sessions are asked to prepare a summary report in magnetic media to be presented at the Closing Session and handled to F. Ruiz.

Wednesday July 28: Field Day (8:15am - Jamaica area)

PROGRAM

Friday 23 - Sunday 25 July:

Arrival to San Jose and transport (on Sunday 25) to hotel in Punta Leona, Costa Rica.

Monday July 26

Moderators: Prof. L. 't Mannetje (am session) and Peter Buurman (pm session).

8:00 - 8:15 am	Welcome to project members and participants.	M. Ibrahim, E. Murgueitio and M.C Amézquita
General		
8:15 - 9:00am	Annual Plan 2004 and summary progress Sep 2003 - July 2004. Key issues for discussion during this meeting.	M. C. Amézquita
9:00 - 9:15am	Discussion	
9:15 - 9:45am	Advances in Socio-economic research (Sep 2003 – July 2004). Summary results by sub-ecosystem.	J. Gobbi
9:45 - 10:00am	Discussion	
10:00- 10:15am	Coffee	
Humid and Sub-humid Tropical Forest, Costa Rica		
10:15 -11:15am	Soil-C and Vegetation-C from long-established systems: General characterisation (climate, systems, soils, biomass and botanical composition). Statistical analysis of SCS data and interpretation.	M. Ibrahim, T. Llanderal, A. Navas
11:15 - 11:45m	Discussion and Recommendations	
11:45 - 12:15m	Socio-economic Evaluation	J. Gobbi
12:15 -12:30pm	Discussion and Recommendations	
12:30 - 2:30pm	Lunch	
Andean Hillsides, Colombia		
2:30 - 3:30pm	Soil Carbon Stocks (SCS) from long-established systems: Evaluations from 1st. and 3rd year. Methods for calculation of SCS.	M.C. Amézquita P. Buurman and H.F. Ramírez
3:30 - 4:00pm	Discussion	
4:00 - 4:15pm	Coffee	
4:15 - 4:45pm	Socio-economic evaluation	Piedad Cuellar
4:45 - 5:00pm	Discussion	
5:00 - 5:30pm	General Recommendations on SCS data and Socio-economic Research – Costa Rica and Andean Hillsides. Carbon definitions.	P. Buurman (mod)

- Moderators of discussion sessions are asked to prepare a summary report in magnetic media to be presented at the Closing Session and handled to F. Ruiz.