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. 7

December 1, 2004 - May 31, 2005

María Cristina Amézquita
Project Scientific Director

Presented to The Netherlands Cooperation, through The Netherlands Embassy in Bogotá, Colombia. June 15, 2005.

PROGRAM

Saturday 14, Sunday 15 and Monday 15 August:
Arrival to Cali Airport and transport to CIAT hotel.

Tuesday 16 August
Moderators: Prof. L. 't Mannetje (am session) and Enrique Murgueitio (pm session).

8:00 – 8:15 am	Welcome to project members and participants	CIAT's Director General
8:15-8:30am	Welcome Address from The Netherlands Cooperation	J. Remmerswaal
General		
8:30 – 9:30am	Project Summary Progress Dec 2001 - August 2005. Key issues for discussion during this meeting.	M. C. Amézquita
9:30–9:45am	Discussion and Recommendations	
9:45-10:00am	Coffee	
Humid and Sub-humid Tropical Forest, Costa Rica		
10:00-11:00am	Soil-C and vegetation-C in long-established systems: Statistical analysis of SCS data from two C-sampling years (2002 and 2004) and interpretation.	M. Ibrahim and T. Llanderal
11:00-11:15m	Discussion and Recommendations	
11:15–12:15pm	Summary Progress in Socio-economic research, Dec 2001- August 2005, all ecosystems. Results from Socio-economic Research, Costa Rica	J. Gobbi
12:15–12:30pm	Discussion and Recommendations	
12:30 – 2:00pm	Lunch	
Andean Hillsides, Colombia		
2:15 – 3:00pm	Soil Carbon Stocks (SCS) from long-established systems: Evaluations from 1st. and 2rd C-sampling years (2002-2004).	M.C.Amézquita, H. Giraldo, HF. Ramírez y ME Gómez
3:00-3:15pm	New ideas emerging from research data	P. Buurman
3:15-3:45pm	Fine Roots biomass vs. SCS	H. Giraldo and HF. Ramírez
3:45 – 4:00pm	Discussion and Recommendations	
4:00 – 4:15pm	Coffee	
4:15 – 4:45pm	Results from Socio-economic research	Piedad Cuellar
4:45 – 5:00pm	Discussion and Recommendations	
7:30 – 8:30pm	Cocktail CIAT VIP's Room	

Wednesday August 17

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

Humid Tropical Forest, Amazonia, Colombia		
8:30 – 9:30am	SCS Evaluation from Long-established Systems and Statistical Analysis (flat and mild-slope topography). 2002- 2005	M. C Amézquita and H.Giraldo
9:30-9:45am	New ideas emerging from research data	Peter Buurman
9:45–10:15am	Root biomass vs. SCS	Bertha Ramírez
10:15- 10:30am	Discussion and Recommendations	
10:30 -10:45am	Coffee	
10:45 -11:15am	Socio-economic Evaluation	B.Ramírez and J. Muñoz
11:15 -11:30m	Discussion and Recommendations	
Economic Simulation Methodology and Results		
11:30 -12:15pm	Economic Simulation – three ecosystems	J. Gobbi
12:15- 12:30pm	Discussion and Recommendations	
12:30 - 2:00pm	Lunch	
Evaluation of Small-plot Experiments – three Sub-ecosystems		
2:30 - 3:00pm	Evaluation of Small-plot Experiment – Esparza, Costa Rica	M.Ibrahim and T. Llanderal
3:00 - 3:15pm	Discussion	
3:15 – 3:45pm	Evaluation of Small-plot Experiments – Dagua and Dovio, 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
4:45 – 5:00pm	General Discussion and Recommendations on Small-plot Experiments data	

- 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.

Thursday August 18: Field Day

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3. Executed Funds of present semester (December 1, 2004 – May 31, 2005) distributed by Activity

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Annex 1: Chronogram of Activities - Annual Plan 2005.

Annex 2: Program VI International Coordination Meeting and Training Course on Green House Gasses (GHG), to be held at CIAT, Cali, on August 16-19 and August 22-24, 2005, respectively.

Annex 3: Complete Statistical Analysis of Soil Carbon Stocks from both C-sampling cycles (2002-2004) - Andean Hillsides Ecosystem, Colombia.

Annex 4: Socio-economic Evaluation Report -Development of Simulation Scenarios

Annex 5: Project Contributed papers at International Congresses 2005: "XXII International Grasslands Congress" (IGC2005), Dublin, Ireland, June 25-July 1, 2005 (two papers) and "II International Energy and Environment Congress" (IEEES2), Kos, Greece, July 3-8, 2005 (one paper)

Annex 6: Contract with ISRIC for extrapolation and GIS maps work

Annex 7: Budget Tables (10): Executed budget (years 1, 2, 3 and first semester of year 4), and projected budget (second semester of year 4, and year 5).

Friday August 19

Moderators: P. Buurman (morning session) and B. Ramírez (pm session)

Future Activities - 2006		
9:00 – 10:00am	New Methodological Tools in the analysis of C Sequestration. Present Recommendations and Future Actions 2006	Bram van Putten
10:00 – 10:15am	Discussion	
10: 15-10:45am	Present state of Project's database. Bio-physical and Socio-economic data from all ecosystems.	H. F. Ramírez and J. Gobbi
10:45-11:00am	Discussion	
11:00–11:15am	Coffee	
11:15-12:00m	General Recommendations on future data analysis – biophysical and socio-economic	All
12:00-2:00pm	Lunch	
Preparation of Recommendations – Closing Session		
2:00-3:30pm	Preparation of a common written report from Session Moderators. Handle Report to Francisco Ruiz	All Session Moderators
3:30-3:45pm	Coffee	
3:15 – 4:00pm	Closing Session: - Presentation of Recommendations from Session Moderators. – Seventh International Coordination Meeting: date and place ?	

- 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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Green House Gasses (GHG) Course

CIAT, August 22-24, 2005
By Dr. Pascal Boeckx
Ghent University, Belgium

Monday August 22
Moderators: E Murgueitio (morning session) and B. van Putten (pm session)

Morning Session		
9:00 - 9:30am	Welcome Address and presentation of participants	M.C.Amézquita
9:30 – 11:30am	Part 1: Agriculture and Environment	P. Boeckx
11:30-11:45am	Coffee	
11:45 – 12:00m	Questions	
12:00-2:00pm	Lunch	
Afternoon Session		
2:00pm – 4:00pm	Part 2: Environmental impact of Climate Change	P. Boeckx
4:00-4:15pm	Coffee	
4:15-4:45pm	Questions	

Tuesday August 23
Moderators: M. Ibrahim (morning session) and B. van Putten (pm session)

Morning Session		
9:00 – 11:00m	Part 3: Greenhouse gas emission and sequestration in terrestrial ecosystems	P. Boeckx
11:00 – 11:15am	Coffee	
11:15- 12:00m	Questions	
12:00-2:00pm	Lunch	
Afternoon Session		
2:00pm – 4:00pm	Part 4: Measurement of GHG emission from terrestrial ecosystems	P. Boeckx
4:00-4:15pm	Coffee	
4:15-5:00pm	Questions	

Wednesday August 24: Field day

- 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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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.7: December 1, 2004 – May 31, 2005"*** reports on project advances during the first semester of the fourth year of project's implementation, in agreement with the project Annual Plan 2005. The most important research activities during this semester were: a) Development of simulation scenarios for farmers' investment, based on previous socio-economic analysis in the project ecosystems (Andean Hillsides, Colombia, Tropical humid forest, Colombian Amazonia, and Sub-humid and humid tropical forest, Costa Rica); b) Completion of field work on soil carbon sampling in Costa Rica ecosystems and in the Humid Tropical Forest, Amazonia, Colombia; c) Complete statistical analysis of Soil Carbon Stocks (SCS) from Andean Hillsides Ecosystems, Colombia; d) Continuation of periodic biomass evaluation of all small-plot experiments established on degraded land in all project ecosystems; and e) Agreement and signature of Terms of Reference with ISRIC, Wageningen for extrapolation and GIS maps work.

Project members 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.

We are pleased to inform that activities conducted and completed during the first semester of our fourth year are in full agreement with the project Annual Plan 2005.

We thank project member and consultants for their fruitful discussions, valuable contributions and efficient work done.

With best wishes for success in the second semester of our project's fourth year.

María Cristina Amézquita
Ph. D. in Production Ecology and Resource Conservation
Project Scientific Director
Cali, Colombia, June 15, 2005.

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)***
  Contracted with ISRIC, Wageningen University, The Netherlands.

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 Amazonia, 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 1st semester year 4 (December 1– May 31, 2005) according to Annual Plan 2005

The activities described below have been successfully accomplished during the first six months of the fourth year of our project: December 1 – May 31, 2005, in accordance with Annual Plan 2005. The Chronogram of Activities 2005 is included as **Annex 1** of the present report.

Technical and administrative coordination activities

1. Project Organisation Activities

In order to successfully start the fourth year of Project implementation, the following activities were performed:

- **Preparation and agreement of annual contracts for project personnel.-** For this fourth year, the project team representing each one of the five member institutions (CIPAV, U. Amazonia, CIAT, CATIE and Wageningen University) remained the same as in the previous three years. The reason for personnel stability has been team coherence, excellent team work and job satisfaction.

- **Preparation and agreement of Terms of Reference for Consultants.-** For this fourth year, the only external consultancy required to cope with project objectives was that on Tropical Grasslands, provided by Professor Leendert 't Mannetje, from Wageningen University. The project is now much more mature in areas such as Soils Science research methodology, and Socio-economic research methodology, making it unnecessary to hire external consultancies on these topics, as required in previous years.

- **Renewal of contracts with farmers on the three Ecosystems.-** At the beginning of the year, contracts with all farmers collaborating with the project in the three project ecosystems, were renewed. In Andean Hillsides ecosystem the number of farms used for project evaluations and socio-economic data gathering are 6 improved farms and 19 conventional farms. In the Humid Tropical Forest, Amazonia, the number of farms used for project evaluations and socio-economic data gathering are 2 improved farms and 22 conventional farms.

In the Humid and Sub-humid Tropical Forest, Costa Rica, the number of farms are 4 improved farms near Esparza, Pacific coast, 4 improved farms near Pocora, Atlantic coast, and 20 conventional farms in both zones.

2. Technical Coordination Activities with all member institutions

- **Preparation of ANNUAL PLAN 2005.-** As agreed with The Netherlands Cooperation, the Annual Plan for each year has to be prepared and handled in January. For this year, the Annual Plan 2005 was prepared and handled to The Netherlands Embassy in Bogotá on January 15, 2005. We are pleased to report that activities completed during the reporting period --first semester of year 4 (December 1, 2004 – May 31, 2005)-- are in complete coherence with the project Annual Plan 2005.

- **Planning of the VI International Coordination Meeting, to be held at CIAT, Cali, Colombia, in August 16-19, 2005.-** The planning of this meeting started already during the first semester 2005. Contents, participants, budget planning, accommodation, field days, etc, were agreed. The Program is included as **Annex 2** of the present report.

- **Planning of a 3-day Training Course on Green House Gasses (GHG), to be held at CIAT on August 22-24, 2005.-** Besides the conduction of the project's VI International Coordination Meeting, a 3-day international training course for project personnel, on Green House Gasses (GHG), offered by Dr. Pascal Boeckx, from Ghent University, Belgium, has been planned for the week immediately following the meeting, that is, for August 22-24, 2005. Thanks to project efforts, Ghent University has agreed to cover all costs of travel and accommodation at CIAT of the lecturer, Dr. Pascal Boeckx. This course will benefit the project as it will provide basic training to project personnel in a complementary subject to Carbon sequestration: measurement and analysis at field level of the three most important GHG (CO_2, Methane, and Nitrous Oxide). Course program is included as **Annex 2** of the present report.

- **Preparation of Seventh Six-months Technical and Financial Reports.-** As stated and agreed in the document "Acuerdo de Contribución", of December 2001, the Seventh Six-months Technical and Financial Report for this period, were prepared and handled to The Netherlands Embassy in Bogotá on June 15, 2005.

Research Activities

- **Completion of the second Carbon sampling cycle (years 2004-2005) in the Humid Tropical Forest Ecosystem, Amazonia, Colombia, and in the Humid and Sub-humid Tropical Forest Ecosystems, Costa Rica.-**

  At the end of this semester, field work related to C evaluation in long-established systems has been completed in all ecosystems. For

Andean Hillsides Ecosystem, the database is ready and the complete statistical analysis of Soil Carbon Stocks (SCS) from both C-sampling cycles (2002-2005) has benn cariied-out. In Amazonia and Costa Rica Ecosystems, laboratory results are ready but the statistical analysis will start during the second semester 2005.

In the Humid Tropical Forest, Amazonia, Colombia, soil carbon and vegetation evaluations on six long-established land use systems, on mild-slope topography ('Pekin Farm") were completed during the present semester. In Costa Rica, all long-established land use systems in Esparza and Pocora were sampled for a second time (years 2004-2005) being the first C-sampling carried-out in 2002, as initially planned. Soil samples from Amazonia were analysed at CIAT's Soils Laboratory. Soil samples from Costa Rica ecosystems were analysed at CATIE's Soils Laboratory. Once lab results are ready and fully checked, the statistical analysis of the complete datasets for both ecosystems will be carried-out. This activity is planned for the 2nd semester 2005.

- **Statistical Analysis of Soil Carbon Stocks from both C-samplings (2002 and 2004): Andean Hillsides Ecosystem, Colombia.-**

In the Andean Hillsides Ecosystem (Dagua and Dovio sites, Colombia) as previously mentioned, field work on both C-sampling cycles (2002 and 2004) was completed at the end of 2004. Therefore, the complete database on this ecosystem is already available. An initial statistical analysis of Soil Carbon Stocks using the complete database from Andean Hillsides Ecosystems was carried-out during this semester. Results will be discussed with all project members during the next VI International Coordination Meeting, to be held at CIAT in August 16-19, 2005. It is possible that as product of discussions, new additional analysis need to be implemented in the future. A summary of results from the statistical analysis is included as **Annex 3** of the present report

- **Socio-economic Research Activities: Development of Simulation Scenarios of farmer's investment in systems with capacity to sequester Carbon - all Ecosystems.**

During this semester, socio-economic results achieved from comparing improved vs. conventional farms in the project ecosystems, have been completed. That is: the project has completed the characterization phase of improved and conventional farms in all ecosystems; has also completed data gathering in terms of cost of inputs and estimation of economic benefit associated with the various land use systems under study. A summary progress report is included as **Annex 4** of the present report.

The new activity that started on the present semester (on May 2, 2005) and will continue up to the end of the project, was the development of simulation scenarios of farmers' investment on systems with Carbon sequestration capacity.

- **Continuation of periodic biomass evaluation of Small-plot Experiments in the three Ecosystems.**

  In order to measure the effect on C sequestration of newly-established improved pasture and silvo-pastoral systems planted on degraded land, five (5) small-plot experiments were established in degraded areas. Those five experiments are: 2 in Andean Hillsides: Dagua and Dovio sites, Colombia; 2 in the Humid Tropical Forest, in flat and mild-slope topographies, Florencia, Amazonia, Colombia; and 1 experiment in Esparza, Sub-humid Tropical Forest ecosystem, Pacific coast, Costa Rica. The initial Cevaluation took place at the beginnings of the project, in the first semester 2002. The final C evaluation will take place at the end of the project.

  In the interim, periodic biomass evaluations carried out every 2-3months, of each improved system studied in the five experiments, has been done to monitor biomass production of improved systems to be later associated with C sequestration.

- **Project collaborative papers at 2005 Congresses: the "XXII International Grasslands Congress (IGC2005) to be held at Dublin, Ireland, June 25-July 1, 2005, and the "II International Energy and Environment Congress" (IEEES2) to be held at Kos, Greece, July 3-9, 2005.**

  Two project papers have been accepted at the "XXII International Grasslands Congress (IGC2005) to be held at Dublin, Ireland, June 25-July 1, 2005. These are: ***Comparison of methodological tools in tropical soil Carbon sequestration field research,*** by B. van Putten and M.C. Amézquita, and ***Carbon sequestration in pasture and silvo-pastoral systems in ecosystems of the Latin American tropics,*** by M. C. Amézquita and M. Ibrahim. They are included as **Annex 5** of the present report.

  One project paper has been accepted at the "II International Energy and Environment Congress" (IEEES2) to be held at Kos, Greece, July 3-9, 2005. It will appear at the congress proceedings and is entitled: ***Pasture Systems in Tropical America: Their Role in C sequestration, Recovery of Degraded Areas and Farmers'Economic Wellfar,***by M.C. Amézquita, H.F. Ramírez and M. Ibrahim. This paper is included as part of **Annex 5** in the present report.

- **Planning Phase: Extrapolation of Project results to similar areas in Tropical America – Contract with ISRIC, Wageningen, The Netherlands**

  An important project objective, stated at "Acuerdo de Contribución" of December 2001, is to extrapolate project results on carbon sequestration levels of pasture, agro-pastoral and silvo-pastoral systems estimated in the project research areas, to similar areas in Tropical America.

To accomplish this goal, it is necessary to work with a geo-referenced database of Tropical America, where each point is represented by its altitude, longitude and latitude, with information on soil type, climate variables (temperature, precipitation) and land use.

ISRIC (International Institute on Soils Research), from Wageningen University, The Netherlands, has developed a geo-referenced database of Tropical America with soil type information at a scale 1:5000. Additionally, CIAT has a database on land use for Tropical America. Discussions between the project Scientific Director, project members from Wageningen University and ISRIC scientists, conducted on April 20-29, 2005, led to an agreement between ISRIC And our Project to start extrapolation work. The Terms of Agreement of the contract with ISRIC have been discussed and signed. Work will start on November 2005 and is expected to end during 2006. ISRIC contract is included in this report as **Annex 6.**

3. Executed Funds during this period (December 1, 2004 – May 31, 2005) distributed by Activity.

Total executed funds during the first semester of year 4 (reporting period December 1, 2004 – May 31, 2005) were US $ 128,181.77. In order to show how executed funds were invested in the various activities conducted during the present reporting period, the next table was prepared, using "Activities" as rows, "Budget Categories" as columns, and % allocated to each activity from the various budget categories as cells. This table is included on the next page.

4. Budget Tables 2005

Budget tables 1-10 are included as **Annex 7** of this report. They show real budget execution for years 1, 2, 3 and first semester year 4, and estimated budget requirements for second semester year 4 and year 5. The tables show project budget --global and per institution-- per year and for the total 5-year of project duration, discriminated by donor funds and matching funds.

Distribution of Executed Funds / Activity - Semester 1 year 4 (December 1, 2004 - May 31, 2005).

Objective	Activities	Category											Total Expenses / Activity. Semester 1, Year 4	
		Lab. Services	Maint. Of Exp	Technical Assist. to Farmers	National Events for Train.& Divulgation	Training Courses to Project Personnel	International Events	Proceed.	Profesional Services	Consulting Services	Operational Cost	Overhead CIPAV	US$	%
		% Distribution of Activity Cost within each Category												
1. PROJECT ORGANISATION ACTIVITIES.	1. Preparation and agreement of annual contracts for project personnel	0	0	0	0	0	0	0	1	0	5	70	3,712.10	2.9
	2. Preparation and agreement of Terms of Reference for Consultants	0	0	0	0	0	0	0	1	0	2	2	987.94	0.8
	3. Renewal of contract with farmers for the three sub-ecosystems: Andean Hillsides, Amazonia and C. Rica farms.	0	0	30	30	0	0	0	3	0	10	28	6,488.80	5.1
2. TECHNICAL AND ADMINISTRATIVE COORDINATION	1. Preparation of ANNUAL PLAN 2005.	0	0	0	0	0	0	20	7	30	10	0	6,665.19	5.2
	2. Planning - VI International Coordination Meeting, CIAT, Aug 29 - Sep 2, 2005	0	0	0	0	0	30	0	3	0	2	0	8,809.98	6.9
	3. Preparation of Seventh Six-months Technical and Financial Reports.	0	0	0	0	0	0	50	10	0	10	0	8,470.32	6.6
3. SOCIO-ECONOMIC SIMULATION	Design and analysis of simulation scenarios. Three Sub-ecosystems	0	0	20	10	50	30	0	5	0	2	0	11,837.96	9.2
4. Continuation of SECOND CARBON SAMPLING in AMAZONIA, COLOMBIA and COSTA RICA SUB-ECOSYSTEMS	1. Soil carbon and vegetation evaluations - six land use systems mid-slope topography, Amazonia - Colombia	35	0	10	25	0	0	0	15	0	15	0	15,341.55	12.0
	2. Soil carbon and vegetation evaluations - second spacial replication, Costa Rica	50	0	10	5	0	0	0	15	0	15	0	15,622.42	12.2
5. STATISTICAL ANALYSIS OF SOIL CARBON STOCKS Both C-samplings: Andean Hillsides sub-ecosystems	Complete Statistical analysis of Soil Carbon Stocks from Andean Hillsides Ecosystems	0	0	0	0	0	0	30	10	50	5	0	8,593.55	6.7
6. EVALUATION OF SMALL-PLOT EXPERIMENTS - BIOMASS PRODUCTION	1. Andean Hillsides-Colombia.	5	33.4	10	10	50	0	0	8	0	7	0	9,666.75	7.5
	2. Humid Tropical Forest - Colombian Amazonia	5	33.3	10	10	0	0	0	8	0	7	0	9,237.25	7.2
	3. Semi humid and humid Tropical Forest - C. Rica	5	33.3	10	10	0	0	0	8	0	7	0	9,237.25	7.2
7. EXTRAPOLATION	Agreement and Signature of TOR with ISRIC, Wageningen, The Netherlands	0	0	0	0	0	40	0	6	20	3	0	13,510.71	10.5
Sum of % expenses / activity within each Category		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**		**100.00**
Total (US$)		**5,921.22**	**5,599.99**	**4,617.14**	**3,036.54**	**847.80**	**21,716.82**	**876.27**	**68,849.86**	**1,744.17**	**11,471.96**	**3,500.00**	**128,181.77**	**100%**
% from total expenses in the semester		**4.6**	**4.4**	**3.6**	**2.4**	**0.7**	**16.9**	**0.7**	**53.7**	**1.4**	**8.9**	**2.7**	**100.0**	**100**

Annex 1

Chronogram of Activities
Annual Plan 2005

Annex 2

Program VI International Coordination Meeting and Training Course on Green House Gasses (GHG)

CIAT, August 16-19 and 22-24, 2005

Annex 3

Statistical Analysis of Soil Carbon Stocks from both C-sampling cycles (2002-2004) - Andean Hillsides Ecosystem, Colombia -

Annex 4

Socio-economic Evaluation Report
Development of Simulation Scenarios

Annex 5

Project Contributed papers at International Congresses 2005

Comparison of Methodological Tools in Tropical Soil Carbon Sequestration Field Research

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Keywords: model, carbon sequestration, extrapolation, land management system, tropical

Introduction

Models play a crucial role in studying complex systems like soil Carbon sequestration processes (Hanson, Schaffer and Ahuja, 2001). A Carbon sequestration research project is currently carried out in pasture and silvo-pastoral systems of four Tropical American ecosystems. A main research question is the identification of Land Management Systems (LMS) that exhibit optimal soil Carbon sequestration capacity (*identification question*). Another main issue is the extrapolation of data in space and time (*extrapolation question*).

Material and Methods

From each of the ecosystems, farms were selected on having long-established LMS of abovementioned type. Soil Carbon stocks (SCS) were measured in permanent plots equidistantly along transects, at four depths, using two space replications per system and 12 sampling points per system/replication. Observations in the corresponding Native Forest (NF) were done following the same lines. In this paper, we compare statistical techniques with techniques based on chemical/biological/physical process knowledge, represented by process-based simulation (PBS) models like CENTURY, RothC, CANDY, DAISY and DNDC.

Results

On optimal allocation of observations within plots will be reported elsewhere. An appropriate statistical technique with respect to *identification* is considering plots of each farm as a random block. As plots are the 'experimental units', the statistically dependent SCS measurements of each plot should be summarized using spatial statistics theory. Statistical inference, based on multiple comparisons hypothesis testing, is possible under the model assumption that, at the farm level, the various LMS were randomly assigned to the plots at the time the NF partially was cleared. Comparison with 'baseline' NF leads to the requested solution. In order to obtain sufficient power of the resulting test, one should take care for having sufficient 'experimental units'.

As PBS models do not deal with experimental error, and consequently cannot discriminate between systematic effects and random variation, they are not appropriate for solving the identification question.

Statistical modelling in principle could be useful for *extrapolation* purposes as well, by using a regression model $y=\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3+\ldots+\epsilon$, where y is SCS, $x_1, x_2, x_3,\ldots$, are outcomes of regressors (among them: 'driving variables'), $\beta_0, \beta_1, \beta_2, \beta_3,\ldots$, are regression coefficients, and ϵ is the experimental error. Prediction of SCS in an unvisited place P is: $(y^\wedge)_P = b_0+b_1(x_1)_P+b_2(x_2)_P+ b_3(x_3)_P +\ldots$, where b_is are least squares estimates, and outcomes of regressors could be found e.g. using GIS. If time is among regressors, prediction in time is possible as well. Predictions can be given including confidence bounds. A disadvantage of the method is that it requires quite a lot of experimental observations in a wide range of experimental conditions (the regressors).

Extrapolation using PBS models requires considerably less observations but a lot of input data instead. Most of PBS models have been developed in temperate zones. It is dangerous to apply them (unmodified) in tropical situation, as turnover rates are higher, and small inaccuracies in the determinants of these rates may have very strong effects on the results (van Keulen, 2001). PBS model predictions are given without any accuracy. In the evaluation of PBS models, existing long-term experiments are usually the only source of data (Powlson, 1996). Just these long-term experiments are associated with difficulties that mainly arise from improper experimental design, improper sampling methods, and poor record keeping (Glendining and Poulton, 1996). In short, application of PBS models for extrapolation purposes goes with a large amount of problems and uncertainties.

Conclusions

If sufficient many data are available, statistical methodology is preferred to using PBS models.

References

Glendining, M.J. and P.R. Poulton (1996). Interpretation Difficulties with Long-Term Experiments. In: D.S. Powlson, P. Smith and J.U. Smith (eds.) Evaluation of Soil Organic Matter Models, using existing long-term datasets. Springer, Berlin, 99-109.

Hanson, J.D., M.J. Schaffer and L.R. Ahuja (2001). Simulating Rangeland Production and Carbon Sequestration. In: R.F. Follett, J.M. Kimble and R. Lal (eds.) The potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. CRC Press LLC, Boca Raton, 345-370.

Powlson, D.S. (1996). Why Evaluate Soil Organic Matter Models? In: D.S. Powlson, P. Smith and J.U. Smith (eds.) Evaluation of Soil Organic Matter Models, using existing long-term datasets. Springer, Berlin, 3-11.

van Keulen, H. (2001). (Tropical) soil organic matter modelling: problems and prospects. *Nutrient Cycling in Agroecosystems*, 61, 33-39.

Abstract presented at the XXII International Grasslands Congress, under the theme "Grasslands and the Environment". Dublin, Scotland, June 26 - July 1, 2005.

Carbon sequestration in pasture and silvo-pastoral systems in ecosystems of the Latin American tropics

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Keywords: tropics, tropical pastures, agroforestry systems, soil carbon stocks

Introduction Conversion of forests to pastures has been the most important land use change in tropical America (TA) in the last fifty years. After deforestation and pasture establishment many areas have been abandoned due to productivity decline arising through mismanagement. Over 60% of the TA's pasture area is degraded. Recent interest in carbon sequestration and environmental considerations might suggest partial reforestation of current pastoral areas but this has implications for the socio-economic welfare of farmers and food availability. However, combining agricultural production with environmental objectives (particularly carbon sequestration) could provide a sustainable alternative. Here we present 3-years of research on the evaluation of soil carbon stocks (SCS) in long-established pasture and silvo-pastoral systems (10-16 years of commercial production) relative to native forest (positive control) and degraded land (reference control) under four ecosystems of TA: Andean hillsides (Colombia), sub-humid and humid tropical forest (Costa Rica) and humid tropical forest, Amazonia (Colombia).

Materials and methods A soil sampling design controlling factors affecting SCS (site conditions, slope or main gradient, land use system, and soil depth) was used. Field research was conducted at farm level, in farmer networks within the project ecosystems. SCS were evaluated at four soil depths (0-10, 10-20, 20-40 and 40-100 cm) using 2 space replications per system and 12 sampling points per system/rep. Total C, oxidisable C, total N, P, CEC, pH, soil texture and bulk density were evaluated at each soil pit and depth. Total, oxidisable and stable C (expressed as the difference between total C and oxidisable C) were corrected for bulk density and expressed as C/ha for each soil depth. Statistical comparisons of SCS between systems were based on fixed soil mass but without subdivision in soil horizons as modified by Buurman *et al.* (2004).

Results Data from Andean hillsides suggests that although native forest possesses the highest SCS in this ecosystem (234 and 186 Mg/ha/1m-equivalent for sites 1 and 2, respectively), improved pasture systems increase SCS when compared to other land use systems. For example, *B. decumbens* with trees (162 and 152 Mg/ha/1m-equivalent for sites 1 and 2) show higher SCS than natural regeneration systems (fallow land and secondary forest, with 156 and 142 Mg/ha/1m-equivalent for sites 1 and 2) and degraded pasture (156 and 97 Mg/ha/1m-equivalent for sites 1 and 2). On the contrary, SCS estimates from the Humid Tropical Forest (Atlantic coast, Costa Rica) show that 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) and this 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. SCS data suggest that in hot and humid environments improved pasture systems show SCS comparable or higher than native forest, therefore representing attractive solutions for C storage.

Conclusions Results suggest that in the tropical ecosystems of Latin America studied, 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). Our research indicates that these systems should be considered as attractive and viable C-improved systems.

References

Amézquita, M.C., M. Ibrahim, L. Tangaxhuan, P. Buurman & E. Amézquita (2004). Carbon Sequestration in Pasture and Silvo-pastoral Systems in four different ecosystems of the Latin American Tropics. *Journal of Sustainable Forestry* (submitted for publication on October 27, 2004).

Amézquita, M. C., P. Buurman, E. Murgueitio & E. Amézquita (2004). Carbon Sequestration Potential of Pasture and Silvo-pastoral Systems in the Tropical Andean Hillsides. 2004. In: R. Lal (ed.) (to be included as a chapter of the book in process of preparation, R. Lal (ed). "Carbon Sequestration Potential in Latin America". The Ohio State University, U.S.A.).

Buurman, P., M. Ibrahim & M.C. Amézquita (2004). Mitigation of greenhouse gas emissions by silvopastoral systems: optimism and facts. In Proceedings of the Second International Congress in Agroforestry, Mérida, Mexico, February 2004.

PASTURE SYSTEMS IN TROPICAL AMERICA: THEIR ROLE IN CARBON SEQUESTRATION, RECOVERY OF DEGRADED AREAS AND FARMERS' ECONOMIC WELFARE

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ABSTRACT
This research aims at identifying pasture systems that provide an economically attractive solution to the farmer and offer environmental services, particularly recovery of degraded areas and C sequestration in Tropical America's ecosystems vulnerable to climate change. Soil C stocks and socio-economic indicators were evaluated. Four-year research results show that improved and well-managed pasture and silvo-pastoral systems represent solutions for the recovery of degraded areas as C-improved systems.

INTRODUCTION
The Kyoto Protocol (Conference of the Parties in its third session, COP3, 1997) and subsequent agreements of the United Nations (COP4 to COP10, 1998-2004) represent a formal world's commitment to decrease atmospheric contamination generated by greenhouse gasses emissions (GHG), particularly CO_2, in the period 2008-2012. These international agreements allow industrialized countries to partially comply with their GHG emission reduction target by offering economic incentives to non-industrialized countries to increase carbon sequestration with live systems. At present, reforestation and afforestation are considered to be land-use systems suitable for economic incentives in developing countries through international carbon trading. However, recent interest in carbon sequestration and preliminary research suggest that improved and well-managed pasture systems in Tropical America (TA) could provide a good combination of economic production, poverty reduction, and delivery of environmental services, particularly carbon sequestration (Veldkamp, 1993 and 1994; Amézquita, 2003; Amézquita *et al*, 2004; Llanderal and Ibrahim, 2004). The approval for European Union countries to contribute to their 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 TA's countries, 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.

TA --comprising Mexico, Central America, The Caribbean and South America excluding Argentina, Chile and Uruguay-- holds 13% of the world's pasture and agro-pastoral land, this representing 77% of TA's agricultural land (FAO, 2000). 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 (CIAT, 1976-2000; Rubinstein and Nores, 1980; Sanint *et al*., 1984; Toledo, 1985; Vera *et al*., 1993; Rivas *et al*., 1998). The major TA's ecosystems where meat and milk are produced are the Savannah (250 million ha), the Tropical Humid and Subhumid Forest (about 44 million ha) and the Tropical Andean Hillsides (96 million ha).

Conversion of forests to pastures has been the most important land use change in TA in the last fifty years (Kaimowitz, 1996). Deforestation is attributed to national policies to alleviate population pressure, 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 and 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, and about 90% of the tropical Andean hillsides pasture's area (CIAT, 1999).

OBJECTIVE
Scientific research on carbon sequestration is been conducted by a long-term project (cited in Acknowledgements) on a range of pasture systems, at farm level, in four ecosystems of TA vulnerable to climate change. Ecosystems studied are: the eroded Andean hillsides of Colombia (densely populated), the humid and sub-humid tropical forest of Costa Rica (densely populated), and the humid tropical forest of the Amazonia in Colombia (strategic environmental region). Research aims at identifying improved and sustainable pasture, agro-pastoral and silvo-pastoral systems that provide a viable and economically attractive solution to the farmer

(alleviating poverty) and offer environmental services, particularly recovery of degraded areas and carbon sequestration (Amézquita, 2002). An 'improved' pasture system has one or more of the following characteristics: appropriate soil/plant management and use of grass, grass-legume, or grass-legume-tree pastures with species that are more productive than local varieties. Previous project publications (Amézquita et al, in press, Amézquita et al, in process for publication) have reported results corresponding to the first C-sampling cycle of long-established systems in some of the ecosystems under investigation, with fieldwork conducted in 2002 and 2003.

This paper discusses four-year research results of the above-mentioned project in two ecosystems: the tropical Andean hillsides (Colombia) and the humid tropical forest (Costa Rica). Research results presented in this paper correspond to two C-sampling cycles of long-established systems, with fieldwork conducted in 2002-2005.

METHODOLOGY

Soil Carbon Stocks (SCS) were evaluated in long-established pasture and silvo-pastoral systems under grazing on commercial farms, 16-18 years after establishment. SCS from pasture systems were compared with those from native forest (positive reference system) and degraded soil (negative reference system). In the tropical Andean hillsides ecosystem, Colombia, evaluation were carried out in six small farms (2-12 ha) located in two sites: Dovio (1900 m.a.s.l., 1800 mm/yr, 140C, high slopes, pH 5.5-6.5, medium fertility soils) and Dagua (1350 m.a.s.l., 1800 mm/yr, 200C, medium slopes, pH 5.0-6.1, less fertile soils). In the humid tropical forest of Costa Rica, evaluations were carried out in four medium-size farms (19-70 ha) located near Pocora, Atlantic coast (200 m.a.s.l., 28-350C, 3500 mm/year, poor acid soils).

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 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 0C. 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 between land-use systems, calculations based on fixed soil mass according to Ellert et al. (2002) and Buurman et al. (2004), were carried-out for total C and stable C, using ANOVA models consistent with the sampling design. The relative importance of factors affecting SCS (land use system, slope gradient and C-sampling cycle) was estimated using ANOVA's SS values, expressing each factor's SS as a percentage of the total SS.

Socio-economic characterization of improved and conventional farms 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 the recovery of degraded areas and carbon sequestration. 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.

RESULTS AND DISCUSSION

Tables 1 and 2 show statistical comparisons of SCS between land use systems using fixed soil mass estimates in the tropical Andean hillsides (Table 1) and in the humid tropical forest (Table 2).

Table 1: SCS (Mg C/ha/1m-equiv) per land Use System. Tropical Andean Hillsides, Colombia Zone 1: Dovio (1900 m.a.s.l.).

Land Use System	Total C	Oxid C	Stable C
Native forest	231 a	163 a	68 a
B. decumbens past	147 b	100 b	47 b
Degraded pasture	136 c	98 b	38 b
Mixed forage bank	131 b	84 c	47 b
Mean	161	111	50
CV (%)	20.0	15.4	41.0
Zone 2: Dagua (1350 m.a.s.l.)			
Land Use System	Total C	Oxid C	Stable C
Native forest	186 a	144 a	42 ab
Secondary forest	155 ab	115 b	40 ab
Nat. regen. (fallow)	142 b	92 c	50 a
B. dec past	136 b	98 b	38 ab
Degraded land	97 c	62 d	35 b
Mixed forage bank	90 c	60 d	30 b
Mean	135	99	40
CV (%)	25.0	15.6	49.0

No. of sampling points/land use system = 24.

Results from the Andean hillsides ecosystem (Table 1) show that for zone 1 (Dovio), with higher altitude, steeper slopes and higher relative fertility, native forest (231 Mg/ha/1m-equivalent) had statistically higher stocks than improved B. decumbens pasture (147 Mg/ha/1m-equi) and this in turn had statistically higher stocks than degraded pasture and forage bank for cut and carrying (136 and 131 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 (155, 142 and 136 Mg/ha/1m-equivalent, respectively, non-statistically different), which in turn had statistically higher stocks than degraded soil and forage bank (97 and 90 Mg/ha/1m-equivalent, respectively). Results suggest that, 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 2: SCS (Mg C/ha/1m-equiv) per Land Use System. Pocora, Humid Tropical Forest, Costa Rica.

Land Use System	Total C	Oxid C	Stable C
I. ciliare pasture	208 a	182 a	26 a
B. brizantha+A. pintoi	194 a	166 b	28 a
A. mangium+A. pintoi	168 b	135 c	33 a
B. brizantha	134 c	120 cd	15 b
Native forest	128 c	111d	17 b
Degraded pasture	94 d	84 e	10 b
Mean	159	135	22
CV (%)	27.0	17.0	49.4

No. of sampling points per land use system = 12.

Results from the humid tropical forest of Costa Rica (Table 2) show that improved pasture systems such as I. ciliare, B. brizantha + A. pintoi and A. mangium + A. pintoi (208, 194 and 168 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). Data suggest that in hot and humid environments improved pasture systems show SCS comparable or higher than native forest, and much higher than degraded pasture, therefore representing attractive environmental solutions for the recovery of degraded areas as C-improved systems.

In both ecosystems studied, "land use system" was the most important factor determining SCS level. In the Andean hillsides ecosystem the second most important factor was "slope gradient". Table 3 shows in this ecosystem that "land use system" and "slope gradient" accounted respectively for 60% and 23% of the variability in total C stocks and 11% and 6% respectively of the variability in stable C stocks.

Table 3: Factors Affecting SCS. Tropical Andean Hillsides.

Factor	df	Total C		Stable C	
		F	SS(%)	F	SS(%)
Sampling Cycle (Y)	1	0.2 ns	0.1	11.4 ***	9.0
System	3	51.3 ***	60.0	9.7 **	23.0
System x Y	3	2.3 *	2.7	0.9 ns	2.0
Slope (System)	12	2.3 **	11.0	0.7 ns	6.2
Y x Slope (System)	12	0.5 ns	2.2	1.1 ns	10.0
Error	64		24.0		49.8
Total	95				
R^2		82%		49%	

***: $p < 0.01$; **: $0.01 \leq p \leq 0.05$; *: $0.05 \leq p \leq 0.10$;
ns: $p \geq 0.10$ SS(%) = (Factor SS/Total SS) x 100.

Although stable C stock estimates showed statistical differences between both C-sampling cycles (2002 vs. 2004) reflecting the high variability in oxidisable C stocks through time, total C stock estimates did not differ between C-sampling cycles confirming the hypothesis that long-established systems under evaluation, due to their age, are thought to have reached equilibrium in their soil carbon accumulation capacity.

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 two ecosystems. Table 4 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 4. Socio-economic Indices of Improved *vs.* Conventional farms. Tropical Andean Hillsides, Colombia.

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

*: 0.05<p<0.10; **: 0.01<p<0.05; ***: p< 0.01.
Source: Amézquita *et al* (in press).

CONCLUSIONS

1. Results from the tropical Andean hillsides ecosystem suggest that in higher altitudes, lower temperatures and relatively better fertility soils, native forest possesses the highest soil carbon accumulation capacity. However, improved pasture systems and natural regeneration (fallow land and

secondary forest) seem good environmental solutions for the recovery of degraded areas, as C-improved systems.

2. Results from the humid tropical forest, on the contrary, show that in hot and humid environments improved pasture systems show SCS higher than native forest, and much higher than degraded pasture, therefore representing attractive solutions for the recovery of degraded areas as C-improved systems.

3. Tropical pasture and silvo-pastoral systems are important socio-economic components of the economies of TA's countries, across all ecosystems. When improved and well managed, they have the capacity to provide viable economic alternatives to farmers and can become key land-use systems for the provision of environmental services, particularly the recovery of degraded areas and carbon sequestration. These systems could be also considered to be land-use systems suitable for international carbon trading and other economic incentives for developing countries.

ACKNOWLEDGEMENTS

Special recognition is expressed to members of the international project *"Research Network for the Evaluation of Carbon Sequestration Capacity of Pasture, Agro-pastoral and 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).

REFERENCES

1. Amézquita, M.C.; Ibrahim, M.; Tangaxhuan, L.; Buurman, P.; Amézquita, E. (In press) Carbon sequestration in pasture and silvo-pastoral systems in four different ecosystems of the Latin American tropics. J. Sustainable Forestry. (Accepted for publication December 2004).
2. Amézquita, M.C.; Buurman, P.; Murgueitio, E.; Amézquita, E. (In process for publication) Carbon sequestration potential of pasture and silvo-pastoral systems in the tropical Andean hillsides. In Lal R., ed. Carbon sequestration potential in Latin America. Ohio State University, Columbus, Ohio, U.S.A.
3. Amézquita, M.C. 2003. Evaluation and Analysis of Carbon Stocks in Pasture, Agro-pastoral and Silvo-pastoral Systems in Sub-ecosystems of the American Tropical Forest. In M.C. Amézquita and F. Ruiz (eds). Two-year Project Achievements. Internal Publication no. 9, Carbon Sequestration Project The Netherlands Cooperation CO-010402, Fourth International Coordination Meeting. December 2003, CIAT, Cali, Colombia.
4. Amézquita, M.C. 2002. Project objectives, expected products and research methodology. In M.C. Amézquita, F. Ruiz and B.van Putten (eds). Carbon Sequestration and Farm Income: Concepts and Methodology. Internal Publication No. 5, Carbon Sequestration Project The Netherlands Cooperation CO-010402, Second International Coordination Meeting, December 2002, CATIE, Turrialba, Costa Rica.
5. Amézquita, M.C., M. Ibrahim and P. Buurman. 2004. Carbon sequestration in pasture, agro-pastoral and silvo-pastoral systems in the American Tropical Forest Ecosystem. In Proc. 2nd Intl. Congress in Agroforestry Systems, Mérida, Mexico, February 2004: 61-72.
6. Browder, J.O. 1988. The social costs of rain forest destruction: a critique and economic analysis of the "hamburger debate". Interciencia 13(3):115-120.
7. Buurman, P., M. Ibrahim and M.C. Amézquita. 2004. Mitigation of greenhouse gas emissions by silvopastoral systems: optimism and facts. In Proc. 2nd Intl. Congress in Agroforestry Systems, Mérida, Mexico, February 2004.
8. CIAT (Centro Internacional de Agricultura Tropical). 1976-2000. Tropical Pastures Program and Tropical Forages Project Annual Reports. Cali, Colombia.
9. CIAT (Centro Internacional de Agricultura Tropical). 1999. Tropical Forages Project Annual Report. Cali, Colombia.
10. Ellert, B.H., H.H. Janzen and T. Entz. 2002. Assessment of a method to measure temporal change in soil carbon storage. Soil Sci. Soc. Am. J. 66:1687-1695.
11. FAO. 2000. Food balance sheets. Rome, Italy.
12. Kaimowitz, D. 1996. Livestock and deforestation Central America in the 1980s and 1990s: a policy perspective. Center for International Forestry Research (CIFOR), Special Publication, Jakarta. pp. 88.
13. Llanderal, T. and M. Ibrahim. 2004. Biophysical Analysis: Advancement Report Sub-humid and humid Tropical Forest, Costa Rica. In Six-months Report no. 5, Internal Document no. 11, Carbon Sequestration Project The Netherlands Cooperation CO-010402, Cali, Colombia.
14. Rivas, L., D. Pachico, C. Seré and J. García. 1998. Evolución y perspectivas de la ganadería vacuna en América Latina Tropical en un contexto mundial. Proyecto de Evaluación de Impacto. CIAT. Cali, Colombia.
15. Rubinstein, E. de and G.A. Nores. 1980. Gasto en carne de res y productos lácteos por estrato de ingreso en doce ciudades de América Latina. CIAT. Cali, Colombia.

16. Sader, S.A. and A.T. Joyce. 1988. Deforestation and trends in Costa Rica, 1940 to 1983. Biotropica 20(1): pp. 11-19.
17. Sanint, L. R., L. Rivas, M.C. Duque and C. Seré. 1984. Food consumption patterns in Colombia: a cross sectional analysis 1981. Paper presented at the Internal Workshop of Agricultural Centers on Selected Economic Research Issues in Latin America. CIAT. Cali, Colombia.
18. Toledo, J. M. 1985. Pasture development for cattle production in the major ecosystems of the tropical American lowlands. In Proc. of the XV Intl. Grasslands Congress, pp. 74-81. Kyoto, Japan.
19. UNFCCC COP10. 2004. United Nations Framework Convention on Climate Change, Conference of the Parties at its tenth session, December 6-17, 2004, Buenos Aires, Argentina.
20. UNFCCC COP9. 2003. United Nations Framework Convention on Climate Change, Conference of the Parties at its ninth session, December 1-12, 2003, Milan, Italy.
21. UNFCCC COP8. 2002. United Nations Framework Convention on Climate Change, Conference of the Parties at its eighth session, October 23 – November 1, 2002, New Delhi, India.
22. UNFCCC COP7. 2001. United Nations Framework Convention on Climate Change, Conference of the Parties at its seventh session, October 29 – November 9, 2001, Marrakech, Morocco.
23. UNFCCC COP6. 2000. United Nations Framework Convention on Climate Change, Conference of the Parties at its sixth session, November 13-24, The Hague, The Netherlands.
24. UNFCCC COP5. 1999. United Nations Framework Convention on Climate Change, Conference of the Parties at its fifth session, October 25 – November 5, 1999, Bonn, Germany.
25. UNFCCC COP4. 1998. United Nations Framework Convention on Climate Change, Conference of the Parties at its fourth session, November 2-13, 1998, Buenos Aires, Argentina.
26. UNFCCC COP3. 1997. United Nations Framework Convention on Climate Change, Conference of the Parties at its third session, December 1-10, 1997, Kyoto, Japan.
27. USDA. 1996. Soil survey laboratory methods manual. Soil Survey Investigations Report No. 42, Version 3, United States Department of Agriculture, Washington D. C., U.S.A., 693 pp.
28. Veldkamp, E. 1993. Soil organic carbon dynamics in pastures established after deforestation in the humid tropics of Costa Rica. Ph. D. Thesis, pp. 117. Wageningen Agricultural University. Wageningen, The Netherlands.
29. Veldkamp, E. 1994. Organic carbon turnover in three tropical soils under pasture after deforestation. Soil Sci. Soc. Am. J. 58: 175-180.
30. Vera, R., J.I. Sanz, P. Hoyos, D.L. Molina, M. Rivera and M.C. Moya. 1993. Pasture establishment and recuperation with undersown rice on the acid soil savannas of South America. CIAT. Cali, Colombia.

Annex 6

Terms of Agreement with ISRIC (International Institute for Soils Research), Wageningen University, The Netherlands

TERMS OF AGREEMENT

1. Introduction

The Carbon Sequestration Project, The Netherlands Cooperation CO-010402 (hereinafter referred to as CSEQ) will make available to the International Soil Reference and Information Centre (hereinafter referred to as ISRIC) a financial contribution in the amount of € 20,204 in support of producing: (1) three digital maps and corresponding paper copies (one per ecosystem: Tropical Andean Hillsides, Sub-humid and Humid Tropical Forest of Central America, and Amazonian Tropical Humid Forest) indicating the regions for extrapolation of the CSEQ's research results in each ecosystem; (2) a database accompanying the maps; (3) a report explaining the methods and results; and (4) presenting the results during the 2006 annual project meeting.

2. Purpose

The funds provided by CSEQ under this Agreement will be used:

(i) To prepare, for the three ecosystems within tropical America that occur in the CSEQ research sites –

(a) *Tropical Andean Hillsides* in Colombia, extending into similar environments in the neighbouring countries of Ecuador, Peru and Bolivia
(b) *Sub-humid and humid tropical forest* at the Atlantic and Pacific coasts of Costa Rica, extending into similar environments in the neighbouring countries of Panama, Nicaragua, Honduras, El Salvador and Guatemala
(c) *Humid Tropical Forest, Amazonia* in Colombia, extending into similar environments in the neighbouring Amazonian countries (Peru, Brazil, Bolivia and Ecuador) -

three digital maps with the corresponding paper copies at scale 1:5 M (one per ecosystem) and accompanying databases. Format of the digital maps will Arc-Info. These will indicate, for each of the ecosystems mentioned sub (i) a, b and c, similar conditions (AEZ, altitude, slope and soil conditions) as in the research sites of CSEQ in these zones. The maps will be based on an analysis of the Soil and Terrain Database for Latin America and the Caribbean (FAO-ISRIC 1998), the SRTM90 digital elevation model (USGS 2003) and the Global Agro-Ecological Zones (FAO-IIASA 2000) for the sub-ecosystems a and b. The extrapolation as mentioned under (c), will be based on the analysis of AEZ and SOTER only, but a subdivision on slopes (2%) will be made to distinguish foothills from the flat areas.

The coordinates of the research sites, the land cover of the research sites, climatic variables and the characterization of their soils in terms of the FAO-Unesco revised legend will be made available to ISRIC.

The resulting maps showing degrees of similarity to the research sites will be overlaid with the Global Land Cover 2000 map (JRC 2000) to calculate land cover per similarity unit.

(ii) To prepare a brief report explaining the methodology and the findings.

(iii) To present the results during the annual project meeting in 2006 at Cali, Colombia

3. Duration and Timing

The total duration of the project is 4 months starting at in November 2005.

4. Products

(1). Digital map and paper copy at scale 1:5 M. of extrapolation region of Tropical Andean Hillsides research results, indicating in different colours those areas under each land cover type.
(2). Accompanying databases
(3). Digital map and paper copy at scale 1:5 M. with extrapolation region of Amazonian Tropical Humid Forest research results, indicating in different colours those areas under each land cover type
(4). Accompanying databases
(5). Digital map and paper copy at scale 1:5 M. with extrapolation region of Sub-humid and Humid Tropical Forest, Costa Rica research results, indicating in different colours those areas covered by each land cover type
(6). Accompanying databases
(7). Final report explaining the methodology and the findings

5. Budget and Payment

The total budget consists of:

GIS work: 25 days @ € 504	= € 12,600.
Query of soil database: 5 days @ € 656	= € 3,280
Reporting: 4 days @ € 656	= € 2,624
Travel and per diem project meeting 2006	= € 1,700
Total	€ 20,204

CSEQ will pay ISRIC € 10,000 in November 2005. The remaining part will be paid at the end of the project, March 2006, after the products have been accepted by CSEQ.

6. Signatures

Date: 28 April 2005
Cali, Colombia,

Dr. María Cristina Amézquita
Scientific Director
Carbon Sequestration Project

Date:28 April 2005
Wageningen, The Netherlands

Sjef Kauffman
Deputy Director
ISRIC – World Soil Information

6 Banking instructions

Account holder	ISRIC World Soil Information
Bank name	ABN Amro Bank
Address	Stadsbrink 43, 6707 AA Wageningen
Postbox	POBox 8, 6700 AA Wageningen
Country	The Netherlands
Account number	41.31.03.196
BIC	ABNANL2A
IBAN	NL32ABNA0413103196

CHRONOGRAM OF ACTIVITIES - ANNUAL PLAN 2005

December 1, 2004 - December 31, 2005

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.A.-CIPAV CATIE
2. TECHNICAL AND ADMINISTRATIVE COORDINATION	Preparation of ANNUAL PLAN 2005.	Plan handled to The Netherland Embassy in Bogotá, Colombia (before December 31, 2004)	■													Project Direction
	VI International Coordination Meeting, CIAT,Cali, Colombia, Aug 29 - Sep 2, 2005	Meeting conducted										■				Project Direction CATIE CIAT CIAPV U.AMAZ. W.U
	Preparation of Seventh Six-months Technical and Financial Reports.	Reports handled to The Netherlands Embassy in Bogotá, Colombia. June 15, 2005.						■	■							All Participant Institutions
	Preparation of Eight Six-months Technical and Financial Reports.	Reports handled to The Netherlands Embassy in Bogotá, Colombia, Dec 15, 2005.											■	■	■	Project Direction CATIE CIAT CIPAV U.AMAZ. W.U
	Preparation of ANNUAL PLAN 2006.	Plan handled to The Netherlands Embassy in Bogotá, Colombia before December 31, 2005.													■	Project Direction and Participant Inst.
3. SOCIO-ECONOMIC SIMULATION	Design and analysis of simulation scenarios. Three Sub-ecosystems	Tool ready. Simulation scenarios analyzed					■					■				Project Direction and CATIE Economics consultant

CHRONOGRAM OF ACTIVITIES - ANNUAL PLAN 2005
December 1, 2004- December 31, 2005
CONT. PAG -2

OBJECTIVE	ACTIVITY	INDICATORS	12	1	2	3	4	5	6	7	8	9	10	11	12	Participant Institutions
4. Continuation of SECOND CARBON SAMPLING in AMAZONIA, COLOMBIA and COSTA RICA SUB-ECOSYSTEMS	1. Soil carbon and vegetation evaluations - six new treatments, Amazonia Colombia (cont. from past semester)	Data organised according to agreed formats														Project Direction U. Amazonia
	2. Soil carbon and vegetation evaluations - second spacial replication, costa Rica (cont. from past semester)	Data organised according to agreed formats														Project Direction CIATIE
5. STATISTICAL ANALYSIS OF Soil Carbon Stocks	1. Complete Statistical analysis on Soil Carbon Stocks from Andean Hillsides Ecosystems															
Both C-samplings: Andean Hillsides and Costa Rica sub-ecosystems	2. Complete Statistical analysis of Soil Carbon Stocks from Costa Rica Ecosystems															
First C-sampling: Amazonia	3. Statistical analysis of Soil Carbon Stocks from First C-sampling, Amazonia															
6. EVALUATION OF SMALL-PLOT EXPERIMENTS - BIOMASS PRODUCTION	Andean Hillsides-Colombia.	Two experiments evaluated every 2 months.														CIPAV CIPAV
	Humid Tropical Forest - Colombian Amazonia	Two experiments evaluated every two months														Univ. Amazonia
	Semi humid and humid Tropical Forest - C. Rica	One experiment evaluated every two months.														CATIE
7. EXTRAPOLATION	1. Agreement and Signature of TOR with ISRIC, Wageningen, The Netherlands 2. Starting of work	Contract with ISRIC signed														Wageningen University, ISRIC and Project Direction

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

Resultados Alcanzados

Al momento de la elaboración de este reporte, el componente socio-económico del proyecto se encuentra en el inicio de la Fase 2, correspondiente a la modelación financiera de los diferentes tipos de usos de la tierra con capacidad para el almacenamiento de carbono. A continuación se presenta una tabla con los resultados alcanzados durante el primer semestre del año 4.

Actividad	
1. Sub-ecosistemas Laderas Andinas, Colombia	
Implementación registros de actividades y producción finca	contínuo
Análisis de la información de los registros de fincas	contínuo
Determinación estructura costos e ingresos por tipo usos suelo	En proceso
Modelos de rentabilidad financiera a nivel de usos de la tierra	En proceso
2. Sub-ecosistemas de la Amazonía, Colombia	
Implementación registros de actividades y producción finca	contínuo
Implementación registros de actividades y producción finca	contínuo
Determinación estructura costos e ingresos por tipo usos suelo	En proceso
Modelos de rentabilidad financiera a nivel de usos de la tierra	En proceso
3. Sub-ecosistemas Bosque Tropical Sumi-Húmedo, Costa Rica	
Implementación registros de actividades y producción finca	contínuo
Implementación registros de actividades y producción finca	contínuo
Determinación estructura costos e ingresos por tipo usos suelo	En proceso
Modelos de rentabilidad financiera a nivel de usos de la tierra	En proceso

1. Introducción

Los sistemas de producción ganadera pueden actuar como emisores o sumideros de carbono. Actúan como emisores de carbono cuando las prácticas de manejo ganaderas resultan en la pérdida de la materia orgánica del suelo (erosión del suelo) o en emisiones directas derivadas de técnicas tradicionales, tales como en las quemas de la cobertura vegetal para promover la regeneración de pastos. Actúan como sumideros cuando se adoptan prácticas de manejo que aumentan la materia orgánica acumulada en el suelo y en la biomasa aérea, tales como la incorporación de árboles en los potreros. Dado el proceso de calentamiento global que está sufriendo el planeta y la importancia social y económica de la ganadería en Latinoamérica (donde las tierras dedicadas a la ganadería cubren más del 60% del terreno agrícola), es necesario identificar sistemas de producción ganadera asociados con sistemas de uso del suelo, que contribuyan a la captura de carbono y que sean económicamente atractivos para los finqueros.

El Proyecto de la "Red de Investigación para la Evaluación de la Capacidad de Almacenamiento de Carbono de Sistemas Pastoriles, Agropastoriles y Silvopastoriles en el Ecosistema del Bosque Tropical Americano" tiene como metas principales el contribuir al desarrollo sustentable, reducir la pobreza y mitigar los efectos indeseables del cambio climático— particularmente las emisiones de CO_2 —en los sub-ecosistemas forestales vulnerables de la América Tropical. Las metas se alcanzan por medio de la investigación en fincas de pequeño y mediano tamaño que presentan un rango de sistemas de pasturas, agro y silvopastoriles localizadas en tres sub-ecosistemas forestales de la América Tropical vulnerables al cambio climático. Estos sub-ecosistemas son: (i) Región de Laderas Andinas de Colombia, (ii) Región de la Amazonía de Colombia y (iii) Región del Bosque Tropical Semi-Húmedo de Costa Rica.

La investigación que se lleva a cabo en las fincas del proyecto está dirigida a identificar sistemas de pasturas, agro y silvopastoriles (SPASP), con capacidad para el secuestro de carbono, que sean financieramente viables para los finqueros de la América Tropical. A tal fin, el componente socio-económico del Proyecto se orienta a evaluar el atractivo económico-financiero de los SPASP con capacidad para el secuestro de carbono, frente a los sistemas ganaderos convencionales de pasturas degradadas. La información generada a partir de los análisis socio-económicos servirá de insumos para la formulación de lineamientos de política para el pago de incentivos por captura de carbono en esos sistemas de manejo de la tierra en el trópico.

En este reporte se presentan un resúmen de los resultados alcanzados en la implementación del monitoreo socio-económico en las fincas del proyecto en los tres sub-ecosistemas. La estructura del reporte es la siguiente. Primero, se presentan los objetivos específicos buscados en el componente socio-económico. Segundo, se detalla la metodología de la Fase 2, correspondiente a la modelación de la viabilidad financiera de los distintos tipos de usos de la tierra con capacidad para el secuestro de carbono. Tercero, se presentan resultados de costos de establecimiento y operación para distintos tipos de usos de la tierra, los que sirven de base para la modelación financiera correspondientes a los tres sub-ecosistemas. Cuarto, se presentan resultados preliminares de modelos de inversión financiera para tres tipos de usos de la tierra. Quinto, se describen las dificultades encontradas para la realización del monitoreo y los modelos. Por último, se discuten los pasos a seguir en el futuro.

2. Objetivos del Componente Socio-Económico

Los objetivos generales del componente socio-económico del Proyecto son: (i) evaluar el atractivo económico-financiero de los SPAPS con capacidad para el secuestro de carbono frente a los sistemas ganaderos convencionales, y (ii) proveer recomendaciones de manejo y de política para hacer dichos SPAPS económicamente atractivos a los finqueros y ambientalmente beneficiosos como sumideros de carbono. En particular, los análisis socio-económicos están orientados a:

- determinar la estructura de costos de inversión y manejo de los SPASP con capacidad para secuestrar carbono, como también sus niveles de producción;
- determinar la rentabilidad financiera de los SPAPS con capacidad para secuestrar carbono frente a los sistemas de ganadería convencional de pastos degradados;

Proyecto Red Captura de Carbono

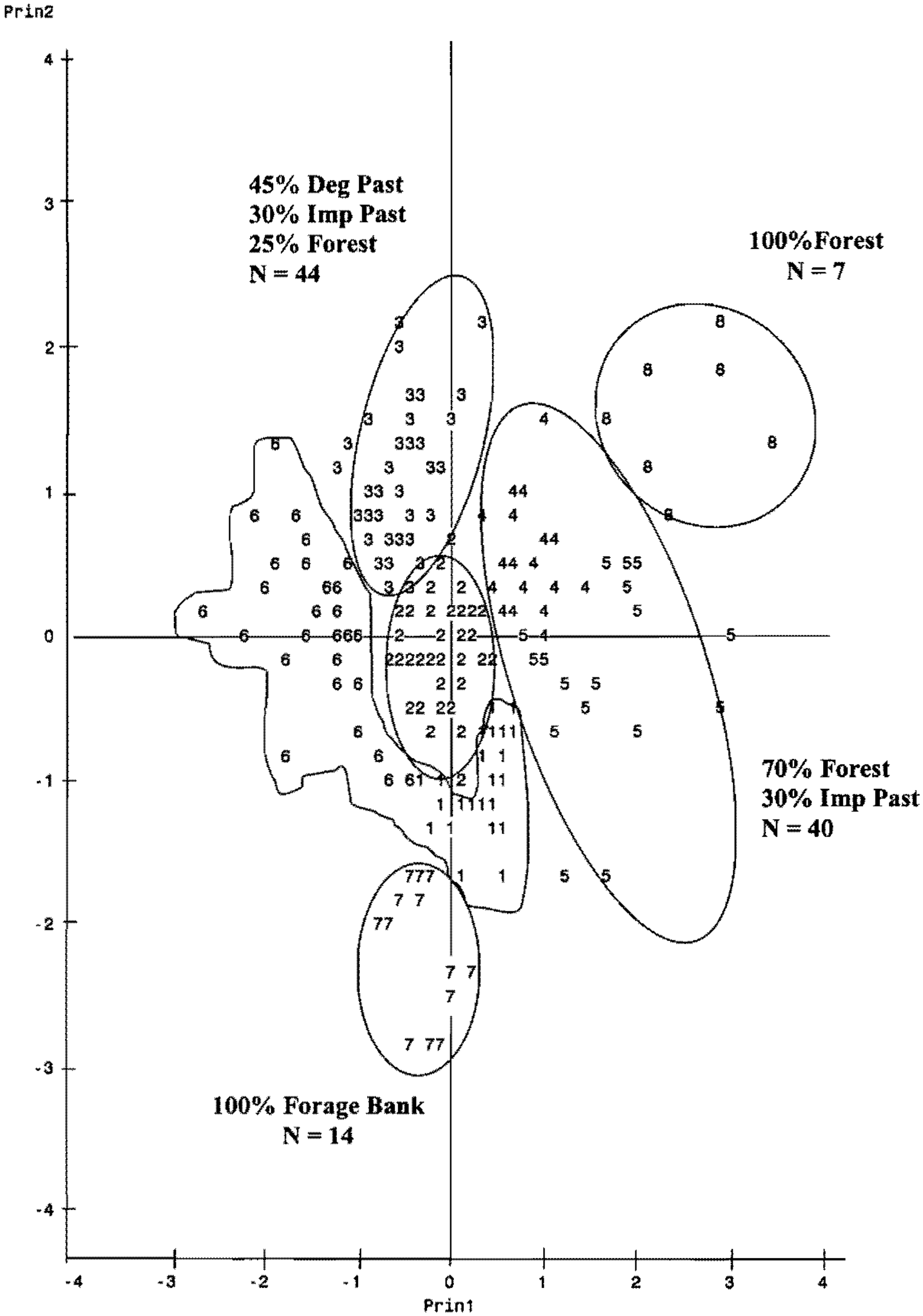
Informe de Avance

Evaluación Socio-Económica de Sistemas Pastoriles, Agropastoriles y Silvopastoriles con Capacidad para la Captura de Carbono

Gobbi, J.; Casasola, F.; Cuellar, P.; Muñoz, J. & Ramírez, B.

Mayo 2005

CLUSTER GROUPS
Based on first two Principal Components



NOTE: 38 obs hidden.

Table 10c: Cluster Description
Zones 1 and 2, two C-sampling years
N=210 soil pits; No. Clusters=8; R^2 = 85%

Cluster (N)	Oxidisable C		Stable C		Cluster Description				
	Min-Max	Mean	Min-Max	Mean	% Forest	% Imp Past	% Deg Past	% Deg Soil	% Bank
8 (N=7)	156-244	192	73-138	105	100	-	-	-	-
5+4 (N=40)	89-237	146	7-105	53	70	30	-	-	-
3 (N=44)	79-151	106	7-111	47	25	30	45	-	-
2 (N=51)	71-203	97	8-83	44	18	33	16	30	-
1+6 (N=54)	18-152	84	11-76	34	11	24	28	22	15
7 (N=14)	32-87	54	7-36	23	-	-	-	-	100

Table 10b: Cluster Groups based on first two PC Zones 1 and 2, two C-sampling years. 8 Clusters, R^2 = 85%, N=210 soil pits

Classification Criteria	CLUSTER NO.							
	1 N=27	2 N=51	3 N=44	4 N=21	5 N=19	6 N=27	7 N=14	8 N=7
Principal Components	**Cluster Means**							
PC1	**0.29**	**-0.08**	**-0.60**	**0.86**	**1.58**	**-1.43**	**-0.32**	**2.45**
PC2	**-1.01**	**-0.15**	**1.06**	**0.57**	**-0.29**	**0.05**	**-2.17**	**1.53**
Original Soil parameters	**Cluster Means**							
Oxidable C (t/ha/1m-equiv)	91	97	106	133	160	76	54	192
Stable C (t/ha/1m-equiv)	38	44	47	58	48	30	23	105
Total N (t/ha/1m-equiv)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Sand (t/ha/1m-equiv)	3003	2236	1369	2500	3552	1237	3074	3017
Clay (t/ha/1m-equiv)	1459	2188	4291	1913	1464	4526	2225	1490
CEC (t/ha/1m-equiv)	147	121	107	124	158	132	212	148

Table 10a: Association between Soil and C variables, based on fixed-mass calculations Zones 1 and 2, two C-sampling years Principal Component Analysis [1] Variance explained 67 %

Variable	PC_1 (39 %)	PC_2 (28 %)
Oxidable C (t/ha/1m-equiv)	0.46 *	0.31
Stable C (t/ha/1m)	0.26	0.44 *
Total N (t/ha/1m-equiv)	0.50 *	0.37
Sand (t/ha/1m-equiv)	0.48 *	-0.46
Clay (t/ha/1m-equiv)	-0.46 *	0.36
CEC (t/ha/1m-equiv)	0.13	-0.47 *

1. Soil and Carbon variable values used in this analysis are accumulated values corresponding to fixed soil mass per zone. (minimum soil mass at 1 m/zone)

PC1: Oxidable C, total N with predominance of sand over clay

PC2: Stable C with predominance of clay over sand

Table 9 (cont): Mean Comparisons for significant Factors (t/ha/1m-equiv)
Site 2: Dagua

Source	Total C		Stable C
	N	$\bar{X}$	$\bar{X}$
Sampling Year (Y)			
• 2002	69	137 a	39 a
• 2004	45	132 a	39 a
Land Use Systems (S)			
• Forest 1	12	186 a	42 ba
• Forest 2	24	155 b	40 ba
• Improved Pasture	24	136 b	38 ba
• Degraded Pasture	24	142 b	50 a
• Forage Bank	18	90 c	30 b
• Degraded Soil	12	97 c	35 b
Position (Land Use System)			
• Forest 2			
1	6	165 a	36 b
2	6	160 a	32 b
3	6	145 a	58 a
4	6	151 a	34 b
• Improved Pasture			
1	6	137 a	37 ab
2	6	142 a	47 a
3	6	135 a	22 b
4	6	131 a	44 a
• Degraded Pasture			
1	6	142 a	58 a
2	6	156 a	56 a
3	6	147 a	50 ab
4	6	123 a	34 b
• Forage Bank			
1	6	72 b	25 a
2	6	92 ba	33 a
3	6	106 a	31 a

Table 9: Mean Comparisons for significant Factors (t/ha/1m-equiv)
Site 1: Dovio

Source	Total C		Stable C
	N	$\bar{X}$	$\bar{X}$
Sampling Year (Y)			
• 2002	48	160 a	43 b
• 2004	48	162 a	57 a
Land Use Systems (S)			
• Native Forest	24	231 a	68 a
• Improved Pasture	24	147 b	47 b
• Degraded Pasture	24	136 c	38 b
• Forage Bank	24	131 c	47 b
Position (Land Use System)			
• Native Forest			
1	6	275 a	83 a
2	6	238 b	69 ba
3	6	203 c	59 b
4	6	207 c	62 b
• Improved Pasture			
1	6	154 a	50 a
2	6	161 a	49 a
3	6	140 a	47 a
4	6	132 a	41 a
• Degraded Pasture			
1	6	148 a	43 a
2	6	132 a	31 a
3	6	118 a	36 a
4	6	147 a	41 a
• Forage Bank			
1	6	140 a	54 a
2	6	130 a	49 a
3	6	126 a	45 a
4	6	127 a	41 a

Table 8 (cont): Factors affecting SCS (t/ha/1m-equiv) Site 2: Dagua

Source	df	Total C			Stable C		
		F	p	SS(%)	F	p	SS(%)
Sampling year (Y)	1	0.1	ns	0.1	0.0	ns	0.0
Land Use System (S)	5	16.7	***	45.0	2.4	*	10.0
S x Y	3	0.5	ns	0.8	2.3	ns	5.4
Position (S)	17	1.2	ns	11.0	1.5	ns	20.0
Y x Position (S)	11	0.5	ns	3.0	0.8	ns	6.4
Error	76			40.1			58.2
Total	113						
Mean		135.1			39.52		
$\sqrt{\sigma^2}$		33.8			19.31		
CV (%) adjusted		25.0			48.85		
R^2		60%			40.8%		

*** $p < 0.01$; ** $0.01 \leq p \leq 0.05$; * $0.05 \leq p \leq 0.10$; ns $p \geq 0.10$;
SS(%) = (Source SS/Total SS) x 100

Table 8: Factors affecting SCS (t/ha/1m-equiv)
Site 1: Dovio

Source	df	Total C			Stable C		
		F	p	SS(%)	F	p	SS(%)
Sampling year (Y)	1	0.2	ns	0.1	11.4	***	9.0
Land Use System (S)	3	51.3	***	60.0	9.7	**	23.0
S x Y	3	2.3	*	2.7	0.9	ns	2.0
Position (S)	12	2.3	**	11.0	0.7	ns	6.2
Y x Position (S)	12	0.5	ns	2.2	1.1	ns	10.0
Error	64			24.0			49.8
Total	95						
Mean		161.1			50.0		
$\sqrt{\sigma^2}$		32.1			20.4		
CV (%) adjusted		19.9			40.8		
R^2		76%			50%		

*** p < 0.01; ** 0.01 ≤p ≤0.05; * 0.05 ≤p ≤0.10; ns p ≥0.10;
SS(%) = (Source SS/Total SS) x 100

Table 7 (cont.): Soil C-Stocks over two C-Sampling years Evaluated at Fixed Depth and Fixed Soil Mass Site 2: Dagua

Soil Depth	Land Use System	Total C		Stable C	
		t/ha/ fixed depth	t/ha/ fixed soil mass	t/ha/ fixed depth	t/ha/ fixed soil mass
0-100 (cm)	Native Forest 1	214 a	186 A	50 b	42 Ba
	Native Forest 2	177 b	155 ba	49 b	40 Ba
	Improved Pasture	162 b	136 b	49 b	38 Ba
	Degraded Pasture	164 b	142 b	65 a	50 A
	Mixed Forrage Bank	111 c	90 c	41 b	30 B
	Degraded Soil	125 c	97 c	54 b	35 Ba
Mean, CV (%), $LSD_{10\%}$		**159, 25,28**	**135, 25, 30**	**52, 54, 23**	**40, 49, 17**
0-40 (cm)	Native Forest 1	122 a	113 A	26 ba	25 A
	Native Forest 2	102 b	91 b	21 b	17 Ba
	Improved Pasture	103 b	83 b	23 ba	18 Ba
	Degraded Pasture	111 ba	89 b	30 a	20 Ba
	Mixed Forrage Bank	67 c	52 c	17 b	12 B
	Degraded Soil	75 c	53 c	20 b	11 B
Mean, CV (%), $LSD_{10\%}$		**98, 26, 17**	**81, 27, 20**	**23, 60, 11**	**18, 51, 8**
40-100 (cm)	Native Forest 1	93 a	43 A	24 b	11 A
	Native Forest 2	75 b	15 b	28 ba	6 A
	Improved Pasture	60 c	16 b	26 b	7 A
	Degraded Pasture	53 dc	12 b	35 a	9 A
	Mixed Forrage Bank	44 d	13 b	24 b	7 A
	Degraded Soil	50 dc	15 b	34 ba	11 A
Mean, CV (%), $LSD_{10\%}$		**62, 34, 14**	**18, 38, 6**	**29, 66, 16**	**8, 74, 5**

- elaborar modelos sobre los efectos de un pago por carbono como incentivo para la adopción de los SPASP con capacidad para secuestrar carbono; y
- proveer de lineamientos de políticas para el pago de incentivos por captura de carbono a finqueros localizados en el bosque tropical americano.

3. Actividades Efectuadas durante el Semestre

Las actividades implementadas durante el presente semestre fueron las siguientes[1]:

- se continuó con el monitoreo de las fincas por medio de los registros de actividades y producción
- se actualizaron los costos de establecimiento de pasturas mejoradas y banco forrajero
- se monitorearon los gastos de mantenimiento de pasturas degradadas, naturales y mejoradas
- se estimaron los gastos de mantenimiento anuales por unidad animal
- se desarrolló la metodología para la modelación de la viabilidad financiera de los usos de la tierra con capacidad para el secuestro de carbono
- en base a los datos provenientes de los registros de finca, se desarrollaron modelos preliminares de inversión de usos de la tierra con capacidad para el secuestro de carbono

4. Resultados

4.1. Metodología para la Elaboración de los Modelos de Análisis Financieros

Se desarrolló la elaboración de los modelos de análisis *ex-ante* de beneficio-costo destinados a evaluar la rentabilidad financiera de invertir en diferentes usos de la tierra con capacidad para la captura de carbono. La misma se describe en el Anexo 1.

4.2. Resultados del Monitoreo Socio-económico de Fincas

4.2.1. Costos de Establecimiento

A continuación se detallan los costos de establecimiento actualizados correspondientes a pasturas mejoradas y de bancos forrajeros para los tres sub-ecosistemas . Los costos se expresan por ha y en dólares estadounidenses. Cabe aclarar que los costos de establecimiento listados son "costos móviles". Esto es, cambian a lo largo del tiempo debido no solo a variaciones en los precios relativos de la mano de obra y los insumos, sino también por: (i) experimentación de los finqueros y técnicos, que tratan de buscar formas de establecimiento de los SSP que sean más baratas y (ii) devaluaciones o apreciaciones nominales de las monedas locales, lo cual influye a la hora de trasladar los costos de establecimiento a dólares. Este último punto ha sido particularmente marcado en el caso de Colombia, donde si bien los costos de establecimiento en pesos permanecieron relativamente constantes, los costos expresados en dólares se han visto

[1] Para una descripción detallada de la metodología del componente socio-económico, véase el documento "Aspectos metodológicos de la evaluación socio-económica de sistemas silvopastoriles, agro-silvopastoriles y silvo-pastoriles con capacidad para el secuestro de carbono". Documento Interno No. 9, Diciembre 2003.

reducidos debido a una apreciación de alrededor del 20% del peso *vis à vis* el dólar durante el año 2004.

Tabla 1. Estimados de los costos de establecimiento de los diferentes usos de la tierra con capacidad para el secuestro de carbono. 2004.

Sub-ecosistema y tipo uso de la tierra	Unidad	[illegible]
Laderas Andinas, Colombia		
Pastura Mejorada	1 ha	655,59
Pastura Mejorada + cercado	1 ha	866,76
Banco forrajero	1 ha	911,11
Banco forrajero + cercado	1 ha	1.122,28
Amazonia, Colombia		
Pastura Mejorada	1 ha	690,30
Pastura Mejorada + cercado	1 ha	847,06
Banco forrajero	1 ha	1074,07
Banco forrajero + cercado	1 ha	313,51
Bosque Sub-húmedo Tropical, Costa Rica		
Pastura Mejorada	1 ha	216,6
Pastura Mejorada + cercado	1 ha	416,6
Bancos Forrajeros mixto de Cratylia y caña de azúcar	1 ha	1339,1
Bancos Forrajeros mixto de Cratylia y caña de azúcar + cercado	1 ha	1539,1

4.2.2. Gastos de Mantenimiento Anual de Pasturas

A continuación se presentan los gastos de mantenimiento anual de diferentes tipos de pasturas, y de los bancos forrajeros correspondientes a cada uno de los sub-ecosistemas. Los montos detallados incluyen los gastos correspondientes a insumos y mano de obra.

Tabla 2. Estimados de los gastos de operación anual de diferentes usos de la tierra. 2004.

[illegible]	[illegible]	[illegible]
Pastura degradada	1 ha	9,3
Pastura natural	1 ha	18,5
Pastura mejorada	1 ha	27,8
Banco forrajero	1 ha	287,4
Amazonía Colombiana		
Pastura degradada	1 ha	13,3
Pastura natural	1 ha	40,0
Pastura mejorada	1 ha	47,8
Banco forrajero	1 ha	63,3
[illegible]		
Pastura degradada	1 ha	12,2
Pastura natural	1 ha	52,1
Pastura mejorada	1 ha	21,8
Banco forrajero	1 ha	290,1

4.2.3. Gastos de Mantenimiento Anual por Unidad Animal

A continuación se presentan los gastos de mantenimiento anual correspondiente a una unidad animal (una vaca y su ternero) en cada uno de los sub-ecosistemas. Los montos detallados incluyen los gastos en insumos (suplementos y vacunas) y en mano de obra (aparte y ordeño).

Tabla 3. Estimados de los gastos de mantenimiento anual de una unidad animal en cada sub-ecosistema. 2004.

[illegible]		[illegible]
Insumos		12,4
Mano de obra		23,0
Total		35,4
Amazonía Colombiana		
Insumos		12,7
Mano de obra		33,3
Total		46,0
Bosque Subhúmedo Tropical Costa Rica		
Insumos		60,4
Mano de obra		36,1
Total		96,5

4.3. Resultados Preliminares de los Modelos de Análisis Financiero

El proyecto ha planteado la hipótesis que existen ciertos tipos de usos del suelo pasturas mejoradas y bancos forrajeros) que capturan mayor cantidad de carbono que las pasturas degradas. En caso que esa hipótesis sea correcta, la condición necesaria para que los finqueros los adopten, es que los mismos sean financieramente rentable. En esta sección se describen los resultados preliminares (sin incorporar ingresos estimados por carbono) de los modelos de inversión financiera de pasturas mejoradas y bancos forrajeros correspondientes a los tres sub-ecosistemas.

La Tabla 4 muestra las tasas internas de retorno (TIR)[2] de la inversión en usos del suelo con capacidad para la captura de carbono. Sin considerar un ingreso potencial por captura de carbono, las TIR indican que la inversión es rentable. Sin embargo, los flujos de caja indican un saldo negativo durante los primeros años de la inversión en todos los casos (Fig. 1 a 9).

Tabla 4. Estimados de rentabilidad de invertir diferentes usos de la tierra con capacidad para el secuestro de carbono. 2004.

Uso original	Cambio a	TIR (%)
Laderas Andinas, Colombia		
Pastura degradada	Pastura mejorada	67,5
Pastura natural	Pastura mejorada	17,5
Pastura mejorada	Banco forrajero mixto*	61,9
Amazonia, Colombia		
Pastura degradada	Pastura mejorada	39,1
Pastura natural	Pastura mejorada	20,1
Pastura mejorada	Past. mejorada + Banco forrajero	26,6
Bosque Sub-húmedo Tropical, Costa Rica		
Pastura degradada	Pastura mejorada	27,2
Pastura natural	Pastura mejorada	38,6
Pastura degradada	Banco forrajero leñosas (gallinaza)**	14,3

* El costo de oportunidad evaluado es la suplementación con Manna.

** El costo de oportunidad evaluado es la suplementación con gallinaza.

[2] En los análisis financieros, la tasa de descuento (TD) es el costo marginal del dinero, el cual está representado por la tasa de interés del crédito a la que el finquero puede obtener dinero (Gittinger 1982). Las tasas reales de descuento para el 2004 en cada uno de los países son las siguientes: Colombia 10-12% y Costa Rica 9-11%.

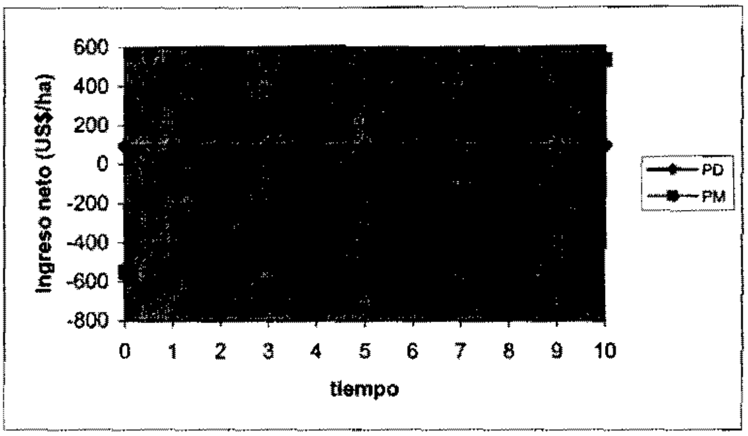


Figura 1. Flujo de caja de la inversión en 1 ha de pasturas mejoradas (PM) a partir de pasturas degradadas (PD). Laderas Andinas, Colombia. 2004.

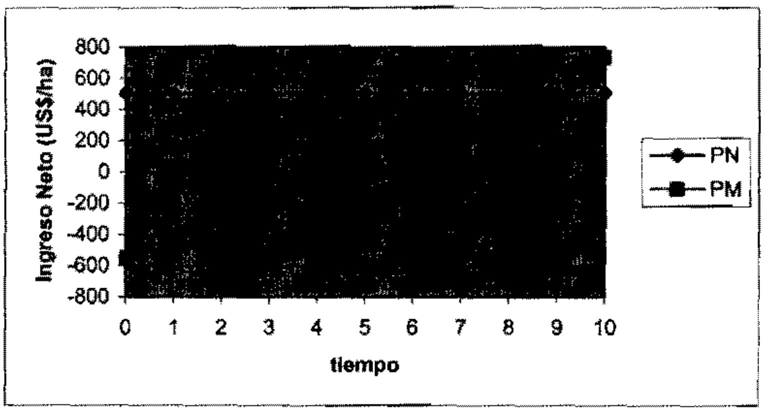


Figura 2. Flujo de caja de la inversión en 1 ha de pasturas mejoradas (PM) a partir de pasturas naturales (PN). Laderas Andinas, Colombia. 2004.

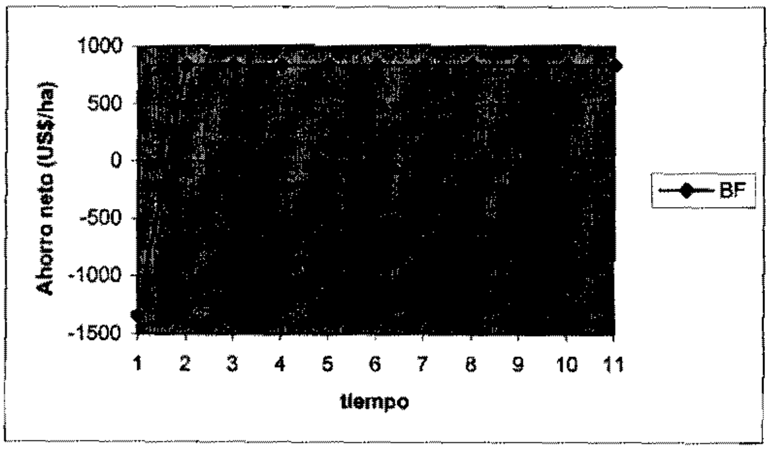


Figura 3. Flujo de caja del ahorro neto asociado a la inversión en 1 ha de banco forrajero, comparado con la alternativa de suplementación con Manna. Laderas Andinas, Colombia. 2004.

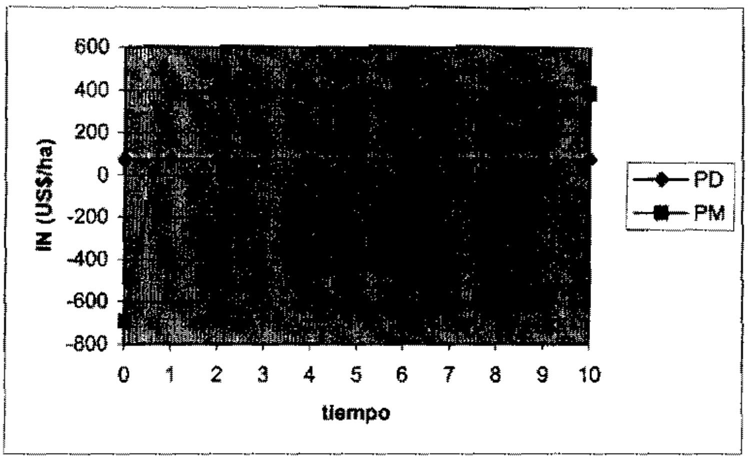


Figura 4. Flujo de caja de la inversión en 1 ha de pasturas mejoradas (PM) a partir de pasturas degradadas (PD). Bosque Húmedo Tropical, Amazonía, Colombia. 2004.

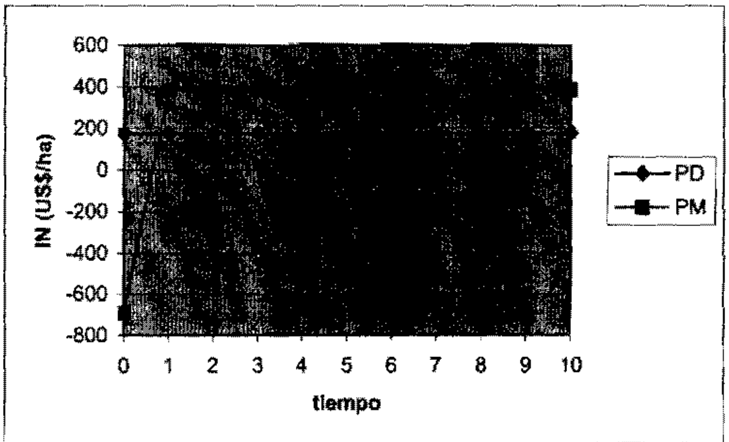


Figura 5. Flujo de caja de la inversión en 1 ha de pasturas mejoradas (PM) a partir de pasturas naturales (PN). Bosque Húmedo Tropical, Amazonía, Colombia. 2004.

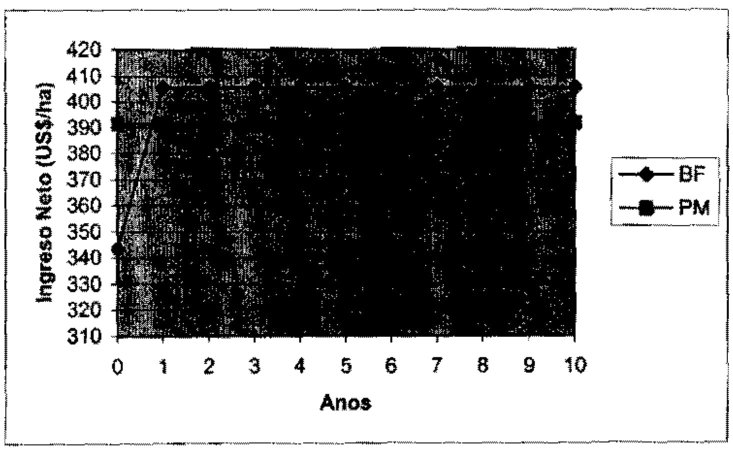


Figura 6. Flujo de caja de la inversión en 1 ha de banco forrajero + pasturas mejoradas (PM) a partir de pasturas mejoradas (PM). Bosque Húmedo Tropical, Amazonía, Colombia. 2004

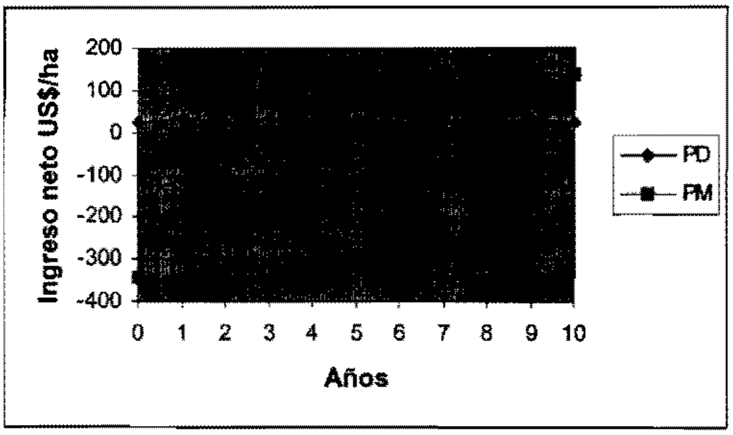


Figura 7. Flujo de caja de la inversión en 1 ha de pasturas mejoradas (PM) a partir de pasturas degradadas (PD). Bosque Sub-húmedo Tropical, Costa Rica. 2004.

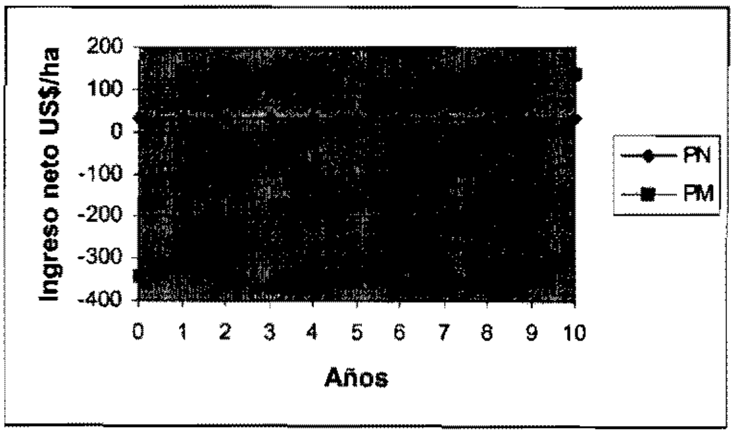


Figura 8. Flujo de caja de la inversión en 1 ha de pasturas mejoradas (PM) a partir de pasturas naturales (PN). Bosque Sub-húmedo Tropical, Costa Rica. 2004.

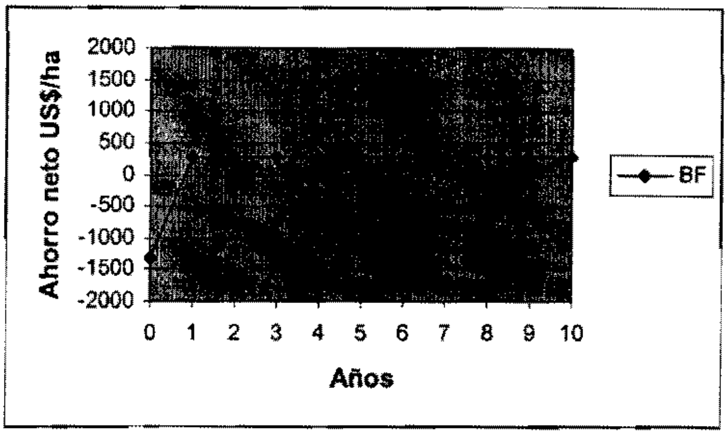


Figura 9. Flujo de caja del ahorro neto asociado a la inversión en 1 ha de banco forrajero, comparado con la alternativa de suplementación con gallinza. Bosque Sub-húmedo Tropical, Costa Rica. 2004.

5. Dificultades Encontradas

En el caso de Colombia, tanto en el sub-ecosistemas de Laderas Andinas como en el de la Amazonía, razones de orden público impidieron que se implementaran los registros en todas las fincas en las que se había planeado llevar los mismos. En la zona de Laderas Andinas, tres productores con fincas piloto abandonaron la zona debido a problemas de seguridad, mientras que en la Amazonía el recrudecimiento del conflicto ha impedido hasta el momento implementar los registros de actividad y producción de las fincas en forma exitosa. Se espera que esa situación se revierta en el futuro mediato. En el caso de Costa Rica, una de las fincas testigo en la que se empezó a llevar registros fue vendida por su dueño, lo que ocasionó la pérdida de dicha información.

6. Próximos Pasos

Los pasos a implementarse durante los próximos seis meses para el componente socio-económico en los tres sitios de investigación del proyecto son los siguientes:

(i) continuar con el monitoreo socio-económico de las fincas;
(ii) refinar los modelos sobre comportamiento financiero de los usos del suelo con capacidad de captura de carbono, incorporando los estimados de captura de carbono para cada tipo de uso de la tierra, y
(iii) efectuar modelaciones incorporando riesgo e incertidumbre.

Anexo 1.

Metodología para la Elaboración de los Modelos Financieros de Inversión

La metodología desarrollada para la formulación de los modelos sigue los lineamientos propuestos por Brown (1979) y Gittinger (1982) para la evaluación de proyectos de inversión en el sector agrícola-ganadero.

Pasos en la Formulación de los Modelos de Análisis Financieros de Inversión

a. Para cada una de los tipos de usos de la tierra con capacidad para el secuestro de carbono se estiman sus costos de establecimiento, parámetros de producción, y gastos de operación y ventas (ingresos) asociados con los misma (la situación "con" el proyecto), y para la situación inicial (la situación "sin" el proyecto, la cual representa el costo de oportunidad del cambio). Para efectuar este paso, se consultan los datos provenientes del monitoreo de fincas y a informantes claves (chapeadores, por ejemplo). Estos estimados de productividad por tipo de uso de la tierra (tales como unidades animales/ha de pastura degradada) se obtienen inicialmente de los registros de finca y se ajustan por medio de consultas con especialistas en cada uno de los países.
b. Se estiman las toneladas de carbono capturadas por cada tipo de uso del suelo y se modela su riesgo de permanencia. Se estima un precio de mercado de la ton de carbono y se lo incorpora como ingreso adicional a la situación "con" el proyecto.
c. Se crean flujos de caja para las situaciones "con" el proyecto (usos del suelo con capacidad para el secuestro de carbono) y para la situación actual de "sin" el proyecto.
d. Se computan los flujos netos incrementales correspondientes a la situación "con" el proyecto versus la situación corriente ("sin" el proyecto, la cual representa en costo de oportunidad del cambio). En base a los flujos netos incrementales se calcula la TIR de la inversión, y se estima el flujo de caja de cada situación.
e. Se conducen análisis de sensibilidad y riesgo para evaluar la robustez de la inversión (adopción) de usos de la tierra con capacidad para la captura de carbono ante cambios en diferentes variables.

Formulación del Flujo de Caja

a. Para normalizar los resultados, los modelos se elaboran a escala de una hectárea.
b. El período del flujo de caja es de 10 años, correspondiente al tiempo de vida útil de las mayoría de los usos de la tierra evaluados.
c. En la construcción del flujo de caja descontado se sigue la convención que todas las transacciones caen al final del período contable. Por lo tanto, las inversiones en los usos del suelo con capacidad para el secuestro de carbono se efectúan al año 0 del proyecto.
d. Los precios de venta de los productos ganaderos y los precios de los insumos se expresan como precios de finca.

e. El flujo de caja se expresa en dólares estadounidenses, con las siguientes tasas de cambio:

- Colombia: 2.595 pesos colombianos = 1 US$
- Costa Rica: 450 colones = 1 US$
- Nicaragua: 15 córdobas = 1 US$

f. Los gastos e ingresos fueron expresados en términos constantes con base en el 2004.

Supuestos Relacionados a la Producción Ganadera

a. La producción ganadera se considera constante en la situación "sin" el proyecto.
b. No se asumen mejoras en los parámetros reproductivos en la situación con el proyecto en los modelos para cambios asociados con pasturas.
d. Se asume que una ha de pastura degradada puede soportar 0,2 unidades animales (UA), una ha de pastura natural 0,5 UA y una ha de pastura mejorada 1 UA.
e. Se asume que el finquero debe cercar 200 metros lineales de ha en la que se cambia el uso de la tierra.

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
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VI INTERNATIONAL COORDINATION MEETING and Green House Gasses Course

CIAT, Cali, Colombia
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CATIE: Centro Agronómico Tropical para Capacitación y Enseñanza, Turrialba, Costa Rica.
Wageningen University and Research Centre, Wageningen, The Netherlands.

Soil Carbon Stocks in Long-established Systems Two C-Sampling years (2002 and 2004)

- Andean Hillsides, COLOMBIA -

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To be presented and discussed at the Project's VI International Coordination Meeting, August 16-19, 2005. CIAT, Cali, Colombia.

Table 1a: Systems Characterisation First C-sampling (2002).

SYSTEM	Age yrs	Slope %	pH	bd gr/cm3	P ppm	N Ppm	CEC meq	Sand %	Clay %
ZONE 1 ("El Ciprés" Farm – DOVIO) 1750 m.a.s.l.; 4°31′N; 76°10′W; 1500mm									
Native Forest – 26 yrs non interv.	26	15–83	5.2	0.65	4.5	5411	33.7	52	18
Impr Past (*Brachiaria decumbens*)	16	27–45	5.8	0.92	7.3	4182	18.4	49	20
Degraded Pasture (King grass)	16	18–52	5.8	0.89	3.8	4310	23.4	46	23
Mixed Forage Bank (5-species)	15	15–45	6.1	0.87	124	3260	19.8	39	25
ZONE 2 (4 Farms in DAGUA - QUEREMAL) 1450 m.a.s.l.; 3°36′N; 76°37′W; 1500mm/year									
Native Forest 1 – 15 yrs regen.	15	47–62	6.5	0.64	8.0	6157	27.7	66	21
Native Forest 2 – 40 yrs non interv.	40	13-57	4.6	0.59	1.1	4464	13.0	30	44
Improved Pasture (*B. decumbens*)	16	25–47	5.3	0.79	0.7	4026	23.0	28	43
Degraded Pasture (*H. rufa*)	40	18–33	5.2	0.83	0.4	3743	23.7	35	38
Mixed Forage Bank (4-species)	14	12–22	6.1	0.90	25	2579	31.1	38	33
Degraded Soil	40	16-20	5.2	1.10	0.6	1.329	17.1	22	54

* Each soil parameter estimate in this table is the mean of 12 laboratory determinations from 12 soil samples taken at 0-10cm depth, on June-August 2002. Soil samples were analysed at CIAT′s Soils Laboratory.

Table 1b: Systems Characterisation Second C-sampling (2004)

SYSTEM	Age yrs	Slope %	pH	bd gr/cm3	P ppm	N Ppm	CEC meq	Sand %	Clay %
ZONE 1 ("El Ciprés" Farm – DOVIO) 1750 m.a.s.l.; 4°31′N; 76°10′W; 1500mm									
Native Forest	28	18-58	5.1	0.61	1.8	5555	33.2	50	26
Improved Pasture (*B. decumbens*)	18	17-35	5.9	0.94	9.7	3336	19.1	45	22
Degraded Pasture (King grass)	18	26-67	5.8	0.70	1.4	4538	32.3	49	23
Mixed Forage Bank (5-species)	17	15-37	6.2	0.98	147	2778	19.5	37	25
ZONE 2 (4 Farms in DAGUA-QUEREMAL) 1450 m.a.s.l.; 3°36′N; 76°37′W; 1500mm/year									
Native Forest 2 – 42 yrs non interv.	42	1.6-52	5.0	0.54	1.1	5131	28.6	49	40
Improved Pasture (*B. decumbens*)	18	23-44	5.5	0.85	1.1	4032	25.2	28	46
Degraded Pasture (*H. rufa*)	42	7-30	5.2	0.78	0.9	3741	17.5	32	43
Mixed Forage Bank (4-species)	16	15-63	5.8	0.88	39.5	2826	32.5	31	34

* Each soil parameter estimate in this table is the mean of 12 laboratory determinations from 12 soil samples taken at 0-10cm depth, on February-May 2004. Soil samples were analysed at CIAT's Soils Laboratory.

Table 2: Land Use History - Information given by the farm owner (last 55 years) -								
SYSTEM	**Initial**	**1950**	**1960**	**1970**	**1977**	**1986**	**1988**	**1988-2005**
ZONE 1 ("El Ciprés" Farm– DOVIO)								
Degraded Pasture	Forest	Sugar cane	Abandnd land	Fruit trees (Tomate de árbol)	Pasture *(Melinis minutif)*	King grass var Taiwan	Degraded King grass + trees + maize +pineapple	Degr. King grass Pasture
Improved Pasture	Forest	Sugar cane	Coffee + Guamo	Fruit trees (idem)	Abandn. Land	*B. decumbens* under grazing		
Mixed Forage Bank	Forest	Maize-beans-sweet-potatoes		Fruit trees + maize	Star grass	5-specie Forage Bank *T. gigantean, M. spp, E. edulis, B. nivea, T. diversifolia.*		
Native Forest	Forest	Forest (intervened)			Forest (non intervened)			

Table 2 (cont.): Land Use History - Information given by the farm owner (last 55 years) - ZONE 2 (4 Farms DAGUA)				
SYSTEM	**Inicial**	**1950**	**1960 - 1977**	**1986 - 2005**
Native Forest 1 – 15 yrs regeneration	Forest	Forest (intervened)		Forest (regenerated)
Native Forest 2 – 40 yrs non intervention	Forest	Forest (intervened)	Forest (regenerated)	Forest (regenerated
Improved Pasture	Forest	Coffee	*H. rufa* pasture	*B. decumbens* under rotational grazing
Degraded Pasture	Forest	*H. rufa* pasture Under grazing		Degraded *H. rufa* pasture.
Mixed Forage Bank	Forest	Coffee	*H rufa* pasture	4-species Forage Bank *T. gigantean, M. spp, E. fusca,* and *T. diversifolia*
Degraded Soil	Native Pasture	Native pasture		Two dominant weed species *Calea spp, Lygodium volubile*

Table 3a: Botanical Composition of Degraded vs. Improved Pasture during the First C-sampling June 2002 (end rainy season)

SYSTEM	**% Bare soil**	**Total DM (kg/ha)**	**BOTÁNICAL COMPOSITION (% in total DM)**			
			Weeds	Main grass	Other grass	Legumes
ZONE 1 ("EL CIPRES" Farm – DOVIO)						
Degr. Past. (under graz)	17.5	2120	18.6 (Sida sp.)	63.5 (King grass)	16.6 *M.minutiflor*	1.3 *Desmodium sp.*
Imp.past (under graz)	0.7	3830	25.6 (Sida sp)	35.4 (*B. decumbens*)	5.7	33..3 (*D.sp.,* *S.guianensis*
ZONE 2 (2 Farms DAGUA-FELIDIA)						
Degr. past (abandoned)	31.5	1280	40.2 *Calea permelli* and Calea *berteruana*	54.5 *A. bicornis,* *A.leucotachyus*	- (*H.rufa*)	5.3% *P. aquilinum,* *B. trineruis*
Imp. Past (under graz)	4.5	2640	4.8	95.2 *(B. decumbens)*	-	-

Table 3b: Botanical Composition of Degr vs. Impr Pasture. 2nd C-sampling. Feb-May 2004 (end rainy season)						
SYSTEM	**% Bare soil**	**Total DM (kg/ha)**	**BOTÁNICAL COMPOSITION (% in total DM)**			
			Weeds	Main grass	Other grass	Legumes
ZONE 1 ("EL CIPRES" Farm – DOVIO)						
Degr. Past. (under graz)	**28**	**938**	**40** *Sida sp*, otros	**35** M. minutiflora	**15** King grass	**10** *Stylosanthes sp*
Imp.past (under graz)	**4**	**1632**	**13** *Speudoeleph antopus*	**75** *B. decumbens*		**2** *Desmodium sp*
ZONE 2 (2 Farms DAGUA)						
Degr. past (abandoned)	**20**	**1625**	**65** *Calea sp, Pteridium cadatum* ,otras	**30** *H. rufa*		**5** *Desmodium sp, Stylosantes*
Imp. Past (under graz)	**4**	**1800**	**7** *Stylosanthes acmella*	**86** *B. decumbens*		**7** *Desmodium sp*

Table 4: Botanical Composition of Mixed Forage Banks 2002 and 2004 C-sampling years. Zone 1: Dovio

Total DM leaves + stems (kg/ha)	**% Botón de oro** *(Thitonia diversifolia)*	**% Morera** *(Morus sp.)*	**% Nacedero** *(Trichanthera gigantea)*	**% Ramio** *(Bohemia nivea)*	**% Chachaf** *(Eritrina edulis)*	**% Pízamo** *(Erytrina fusca)*	**% Gamboa** *(Smallanthus riparius)*
First C-sampling (2002)							
4505	20.7	38.5	32.3	-	8.5	-	-
Second C-sampling (2004)							
7486	23.1	38.5	15.4	23.1	-	-	-

DM values and botanical composition were calculated from 10 samples of $3m^2$ at C-samplig time

Table 4 (cont): Botanical Composition of Mixed Forage Banks. 2002 and 2004 C-sampling years.
Zone 2: Dagua

Total DM leaves + stems (kg/ha)	% Botón de oro *(Thitonia diversifolia)*	% Morera *(Morus sp.)*	% Nacedero *(Trichanthera gigantea)*	% Ramio *(Boehmeria nivea)*	% Chachaf *(Erythrina edulis)*	% Pízamo *(Erytrina fusca)*	% Gamboa *(Smallanthus riparius)*
First C-sampling (2002)							
6752	9.0	7.4	62.5	-	-	19.0	2.1
Second C-sampling (2004)							
5567	-	16.0	56.0	-	-	24.0	4.0

DM values and botanical composition were calculated from 10 samples of $3m^2$ at C-samplig time

Table 5: Soil Carbon Stocks (t/ha/fixed depth) from two C-Sampling years – Site 1: Dovio

Soil Depth	Land Use System	Total C			Stable C		
		1st C-Sampling	2nd C-Sampling	$\overline{X}$	1st C-Sampling	2nd C-Sampling	$\overline{X}$
0-100 (cm)	Native Forest	262 a	290 a	276 a	79 a	97 a	88 a
	Improved Pasture	213 b	195 b	204 b	55 ba	92 a	73 ba
	Degraded Pasture	183 bc	148 c	166 c	46 b	49 b	47 c
	Mixed Forrage Bank	161 c	176 cb	168 c	58 ba	77 a	67 b
Mean, CV (%), $LSD_{10\%}$		**205, 21, 36**	**202, 20, 34**	**203, 21 24**	**59, 47, 23**	**78, 43, 28**	**69, 45, 18**
0-40 (cm)	Native Forest	170 a	165 a	167 a	48 a	39 a	43 a
	Improved Pasture	136 b	121 b	128 b	29 b	46 a	37 a
	Degraded Pasture	122 cb	95 c	109 c	28 b	27 b	28 b
	Mixed Forrage Bank	106 c	118 b	112 c	32 ba	43 a	38 a
Mean, CV (%), $LSD_{10\%}$		**134, 24, 27**	**125, 15, 16**	**129, 20, 20**	**34, 56, 16**	**34, 56, 16**	**36, 42, 12**
40-100 (cm)	Native Forest	92 a	125 a	109 a	32 a	58 a	45 a
	Improved Pasture	77 ba	74 b	76 b	26 a	46 ab	36 ba
	Degraded Pasture	62 bc	53 b	57 c	18 a	22 c	20 c
	Mixed Forrage Bank	54 c	58 b	56 c	26 a	34 cb	30 cb
Mean, CV (%), $LSD_{10\%}$		**71, 27,16**	**77, 36, 23**	**74, 32, 18**	**25, 67, 14**	**40, 69, 23**	**32, 70, 18**

Table 5 (cont.): Soil Carbon Stocks (t/ha/fixed depth) from two C-Sampling years - Site 2: Dagua

Soil Depth	Land Use System	Total C			Stable C		
		1st C-Sampling	2nd C-Sampling	$\overline{X}$	1st C-Sampling	2nd C-Sampling	$\overline{X}$
0-100 (cm)	Native Forest 1	214 aa	-	214 a	50 b	-	50 ba
	Native Forest 2	177 b	177 a	177 b	48 b	51 a	49 ba
	Improved Pasture	165 b	159 a	162 b	42 b	56 a	49 ba
	Degraded Pasture	171 b	158 a	164 b	78 a	52 a	65 a
	Mixed Forrage Bank	104 c	118 a	111 c	36 b	47 a	41 b
	Degraded Soil	125 c	-	125 c	54 b	-	54 ba
Mean, CV (%), LSD $_{10\%}$		**162, 27, 37**	**155, 20, 27**	**159, 25,28**	**52, 54, 23**	**52, 39, 18**	**52, 48, 17**
0-40 (cm)	Native Forest 1	122 a	-	122 a	26 ba	-	26 ba
	Native Forest 2	102 a	101 a	102 b	16 b	26 a	21 ba
	Improved Pasture	109 a	96 a	103 b	25 ba	21 a	23 ba
	Degraded Pasture	119 a	104 a	111 ba	35 a	24 a	30 a
	Mixed Forrage Bank	68 b	66 b	67 c	16 b	19 a	17 b
	Degraded Soil	75 b	-	75 c	20 b	-	20 b
Mean, CV (%), LSD $_{10\%}$		**100, 28, 23**	**94, 23, 19**	**98, 26, 17**	**23, 60, 11**	**23, 40, 8**	**23, 53, 8**
40-100 (cm)	Native Forest 1	93 a	-	93 a	24 b	-	24 a
	Native Forest 2	75 a	76 a	75 b	32 ba	25 a	28 a
	Improved Pasture	56 b	63 ba	60 c	17 b	35 a	26 a
	Degraded Pasture	53 cb	54 b	53 dc	43 a	28 a	35 a
	Mixed Forrage Bank	36 c	52 b	44 d	20 b	27 a	24 a
	Degraded Soil	50 cb	-	50 dc	34 ba	-	34 a
Mean, CV (%), LSD $_{10\%}$		**61, 36, 19**	**62, 31, 17**	**62, 34, 14**	**29, 66, 16**	**29, 51, 13**	**29, 60, 12**

Table 6: Soil Carbon Stocks (t/ha/fixed soil mass) on two C-Sampling years

Site 1: Dovio

Soil Depth	Land Use System	Total C			Stable C		
		1st C-Sampling	2nd C-Sampling	$\overline{X}$	1st C-Sampling	2nd C-Sampling	$\overline{X}$
0-100 (cm)	Native Forest	217 a	245 a	231 a	62 a	74 a	68 a
	Improved Pasture	151 b	142 b	147 b	34 b	59 ba	47 b
	Degraded Pasture	145 b	128 b	136 b	34 b	41 c	38 b
	Mixed Forrage Bank	127 b	135 b	131 b	42 b	53 bc	47 b
Mean, CV (%), LSD $_{10\%}$		**160, 23, 30**	**162, 17, 23**	**161, 20, 18**	**43, 50, 18**	**57, 34, 16**	**50, 41, 16**
0-40 (cm)	Native Forest	133 a	139 a	136 a	33 a	32 a	32 a
	Improved Pasture	89 b	84 b	86 b	17 b	26 b	21 b
	Degraded Pasture	90 b	82 b	86 b	19 b	23 b	21 b
	Mixed Forrage Bank	69 c	76 b	73 c	17 b	24 b	20 b
Mean, CV (%), LSD $_{10\%}$		**95, 23, 18**	**96, 15, 12**	**95, 19, 11**	**22, 46, 8**	**26, 26, 6**	**24, 35, 6**
40-100 (cm)	Native Forest	31 b	50 a	40 a	12 ba	22 a	17 a
	Improved Pasture	39 a	31 b	35 b	13 a	19 a	16 a
	Degraded Pasture	22 c	13 c	18 c	7 ba	5 b	6 b
	Mixed Forrage Bank	13 d	19 c	16 c	6 b	11 b	8 b
Mean, CV (%), LSD $_{10\%}$		**26, 30, 6**	**28, 34, 8**	**27, 32, 5**	**10, 76, 6**	**14, 70, 8**	**12, 72, 7**

Table 6 (cont.): Soil Carbon Stocks (t/ha/fixed soil mass) on two C-Sampling years Site 2: Dagua

Soil Depth	Land Use System	Total C			Stable C		
		1st C-Sampling	2nd C-Sampling	X̄	1st C-Sampling	2nd C-Sampling	X̄
0-100 (cm)	Native Forest 1	186 a	-	186 a	42 ba	-	42 ba
	Native Forest 2	152 b	158 a	155 ba	37 b	43 a	40 ba
	Improved Pasture	142 b	130 b	136 b	35 b	40 a	38 ba
	Degraded Pasture	147 b	137 ba	142 b	59 a	40 a	50 a
	Mixed Forrage Bank	86 c	94 c	90 c	26 b	34 a	30 b
	Degraded Soil	97 c	-	97 c	35 b	-	35 ba
Mean, CV (%), LSD $_{10\%}$		**137, 27, 31**	**132, 21, 24**	**135, 25, 30**	**39, 54, 18**	**40, 39, 13**	**40, 49, 17**
0-40 (cm)	Native Forest 1	113 a	-	113 a	25 a	-	25 a
	Native Forest 2	90 b	91 a	91 b	12 b	22 a	17 ba
	Improved Pasture	89 b	78 a	83 b	21 ba	15 b	18 ba
	Degraded Pasture	93 ba	85 a	89 b	22 a	18 ba	20 ba
	Mixed Forrage Bank	52 c	51 b	52 c	11 b	13 b	12 b
	Degraded Soil	53 c	-	53 c	11 b	-	11 b
Mean, CV (%), LSD $_{10\%}$		**83, 29, 20**	**78, 24, 16**	**81, 27, 20**	**17, 60, 9**	**18, 34, 5**	**18, 51, 8**
40-100 (cm)	Native Forest 1	43 a	-	43 a	11 a	-	11 a
	Native Forest 2.	18 b	12 b	15 b	8 ba	5 b	6 a
	Improved Pasture	14 b	18 a	16 b	4 b	10 a	7 a
	Degraded Pasture	14 b	11 b	12 b	11 a	6 b	9 a
	Mixed Forrage Bank	11 b	14 b	13 b	6 ba	8 ba	7 a
	Degraded Soil	15 b	-	15 b	11 a	-	11 a
Mean, CV (%), LSD $_{10\%}$		**20, 41, 7**	**14, 26, 3**	**18, 38, 6**	**9, 83, 6**	**7, 48, 3**	**8, 74, 5**

Table 7: Soil Carbon Stocks over two C-Sampling years Evaluated at Fixed Depth and Fixed Soil Mass
Site 1: Dovio

Soil Depth	Land Use System	Total C		Stable C	
		t/ha/ fixed depth	t/ha/ fixed soil mass	t/ha/ fixed depth	t/ha/ fixed soil mass
0-100 (cm)	Native Forest	276 a	231 a	88 a	68 A
	Improved Pasture	204 b	147 b	73 ab	47 B
	Degraded Pasture	166 c	136 b	47 c	38 B
	Mixed Forrage Bank	168 c	131 b	67 b	47 B
Mean, CV (%), LSD 10%		**203, 21, 24**	**161, 20, 18**	**69, 45, 18**	**50, 41, 16**
0-40 (cm)	Native Forest	167 a	136 a	43 a	32 A
	Improved Pasture	128 b	86 b	37 a	21 B
	Degraded Pasture	109 c	86 b	28 b	21 B
	Mixed Forrage Bank	112 c	73 c	38 a	20 B
Mean, CV (%), LSD 10%		**129, 20, 20**	**95, 19, 11**	**34, 56, 16**	**24, 35, 7**
40-100 (cm)	Native Forest	109 a	40 a	45 a	17 A
	Improved Pasture	76 b	35 b	36 ba	16 A
	Degraded Pasture	57 c	18 c	20 c	6 B
	Mixed Forrage Bank	56 c	16 c	30 cb	8 B
Mean, CV (%), LSD 10%		**74, 32, 18**	**27, 32, 5**	**32, 70, 18**	**12, 72, 7**