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

Final Technical Report

December 1, 2001 - November 30, 2006

Presented to The Netherlands Cooperation through The Netherlands Embassy in Bogotá, Colombia, on January 15, 2007

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1. Project Scientific Book (English)
2. Book for Farmers, Educators and Students (Spanish)
3. Project Video (Spanich)
4. Project Video (English)

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 5-year project, which ended past November 30 2006.

Our project combined 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 goal was to achieve relevant high quality research results that will contribute to decision-making directed towards the mitigation of the adverse effects of global warming in vulnerable ecosystems of Tropical America.

The present document ***"Final Technical Report: December 1, 2001 – November 30, 2006"*** presents project objectives *vs.* project achievements in the 5-years of project implementation, in agreement with our Annual Plans 2002-2006.

We thank project members and consultants for the high scientific quality of the work done. We also thank the distinguished group of decision-makers from the Colombian Government invited to participate to our international coordination meetings in August 2005 and October 2006, for their contributions and ideas on how project resuts help the decion-making process related to Climate Change and Environmental Policy.

With our best wishes for future success.

María Cristina Amézquita
PhD, Production Ecology and Resource Conservation
Project Scientific Director
Cali, Colombia, January 15, 2007

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Research Services

- ***Laboratory analyses***
  Samples from Colombian ecosystems: contracted with CIAT's Soils Laboratory.
  Samples from Costa Rica ecosystem: contracted with CATIE's Soils Laboratory.
- ***GIS (cartography and Extrapolation study)*** contracted with ISRIC, Wageningen, The Netherlands.

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Wageningen University and Research Centre.

The Netherlands Cooperation:
Activity CO-010402
(2001-2006)

Qué aportó nuestro Proyecto en sus 5 años de implementación?

Nuestro Proyecto, de naturaleza internacional, multi-institucional y multi-ecosistema, aborda un tema de investigación de interés mundial --Cambio Climático: medidas de mitigación y adaptación en ecosistemas vulnerables en países en desarrollo--. Los productos más importantes de nuestro proyecto son:

(a) Sus resultados científicos sobre la capacidad de Captura de C y beneficio socio-económico al productor de sistemas mejorados y bien manejados de pasturas y silvo-pastoriles, comparados con el bosque nativo (referencia positiva) y el suelo degradado (referencia negativa) en cuatro ecosistemas tropicales vulnerables al Cambio Climático. Nuestro Proyecto ha producido información científica sólida en este tema, para contribuir a la toma de decisiones.
(b) La metodología que hemos generado para la evaluación, estimación y análisis de la "Captura de C" en estos usos del suelo. Nuestros Informes Técnicos (10), nuestro Libro Científico, la Cartilla para Productores, Educadores y Estudiantes, el video del Proyecto en Español y en Inglés, y nuestras publicaciones científicas nacionales e internacionales ilustran estos resultados.

Nuestro proyecto busca abrir una nueva puerta para paises en desarrollo y es la de entregar información científica sólida que permita a la UNFCCC incluír en las políticas del mercado internacional de Carbono para el próximo período de implementación del Protocolo de Kyoto (20012-20020) los sistemas mejorados de pasturas y silvopastoriles. Nuestro proyecto entrega informción que demuestra que éstos sistemas, ademas de ser economicamente atractivos al productor en su potencial de generación de empleo, de producción de carne y de producción de leche, son ambientalmente benéficos en su capacidad de oferta de servicios ambientales, en particular, la captura de carbono.

Beneficios adicionales a las instituciones socias

Adicionalmente, las instituciones socias se han beneficiado en diferentes formas, por Ej:

La Universidad de la Amazonia, por ser miembro activo de un proyecto como el nuestro, logró la acreditación de dos de sus programas: Agroforestería y Agronomía. El Rector está agradecido por este beneficio institucional. Además nuestro Proyecto ha contribuido a la capacitación y desarrollo profesional de 3 docentes y 7 estudiantes.

Nuestro Proyecto ha contribuido a la capacitación y desarrollo profesional de 2 investigadores y de 2 Co-investigadores asociados con **CIPAV**. Uno de ellos, el Sr. Julián Giraldo, dueño de una de las fincas donde realizamos las evaluaciones en El Dovio, está motivado a seguir la carrera de investigación científica. El folleto para productores, educadores y estudiantes que produjo el Proeycto, en donde se explica en forma muy didáctica el tema de Cambio Climático y de Captura de Carbono, representa una valiosa contribución al país y a otros países de habla Hispana.

Nuestro Proyecto ha permitido la formación a nivel Doctoral de dos profesionales latinoamericanos que están adelantando su tesis en el marco de nuestro Proyecto: el Sr. Tangaxuhan Llanderal, Mexicano, afiliado al **CATIE**, y el Sr. Octavio Mosquera, Colombiano, afiliado al **CIAT**. **La Universidad de Wageningen** se beneficia ya que uno de los estudiantes adelanta su Doctorado en dicha Universidad.

Adicionalmente, nuestro Proyecto ha permitido la formación y capacitación de varios estudiantes de Maestría y pregrado del **CATIE**; dos estudiantes de la **Universidad Javeriana, Bogotá**; una estudiante de la **Universidad Santo Tomás, Cali**; una estudiante de la **Universidad de Montpellier, Francia**; y de una estudiante de la **Universidad de Ghent, Bélgica**, quien desarrolló su tesis de pre-grado en Biología, con trabajo de campo en la evaluación de dos de los Gases de Efecto Invernadero (CO_2 y Oxido Nitroso) en sistemas de uso del suelo en Dagua, Laderas Andinas, Colombia.

Hemos logrado publicar a nivel internacional (New York Press, Ohio State University, International Agroforestry Journal, y en las Memorias de importantes Congresos en el tema general de Cambio Climático) resultados parciales de nuestro Proyecto. Hemos logrado también reconocimiento a nivel nacional. Los nombres CIPAV, Universidad de la Amazonía, CIAT, CATIE y Universidad de Wageningen, junto con el de la Cooperación Holandesa, aparecen en todas nuestras publicaciones internacionales y nacionales.

El Gobierno de Colombia a través del IDEAM (Instituto de Investigación en Hidrología, y Recursos Ambeintales) adscrito al Ministerio del Medio Ambiente, nos invitó a extender nuestro Proyecto a tres nuevos ecosistemas en Colombia: Páramo, Sabana y Piedemonte Inter-andino.

Relación del Proyecto con La Cooperación Holandesa a través de la Embajada de Holanda en Colombia

Gracias a la excelente coordinación inter-institucional y al serio y cumplido trabajo de todos los miembros, nuestro Proyecto ha sido muy exitoso. La heterogeneidad entre las instituciones participantes ha representado un aspecto positivo, ya que cada socio ha aportado su conocimiento y experiencia específicos para bien del Proyecto, y nos ha enseñado a todos que hay muchas maneras distintas de aportar a la solución de un problema. Hemos cumplido año por año nuestros Planes Anuales a cabalidad. Los objetivos inicialmente planteados por nuestro Proyecto se han ido cumpliendo con la requerida solidez científica.

Debido a nuestro cumplimiento y calidad en los resultados, y a la alta eficiencia y apoyo permanente a nuestro Proyecto por parte de los funcionarios de La Embajada de Holanda en Bogotá Srs. Vincent van Zeijst, Jaques Remmerswaal, Maurice van Beers y Wilson Tovar, la Cooperación Holandesa nunca ha rechazado o devuelto alguno de nuestros Informes Técnicos o Financieros, y como resultado, sus desembolsos financieros siempre han estado a tiempo. La gestión de CIPAV como Administrador Financiero ha sido ágil, transparente e impecable. En mi nombre y en de las instituciones participantes agradecemos mucho al Dr. Enrique Murgueitio, Direcxtor Ejecutivo de CIPAV, y a su personal administrativo por su trabajo en éste aspecto tan delicado de la vida de un proyecto.

La Cooperación Holandesa se ha manifestado complacida con nuestro proyecto. Hasta ahora hemos cumplido con los objetivos propuestos y lo hemos hecho con calidad. Y nosotros nos hemos sentido apoyados, motivados, y estimulados a trabajar con entusiasmo y alta calidad por parte de la Cooperación Holandesa.

Una vez más, mil gracias a La Cooperación Holandesa por su apoyo.

Cordialmente,

María Cristina Améquita
Directora Científica del Proyecto

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 Tropical America. This main goal is 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 four ecosystems of the American Tropics vulnerable to climate change: the eroded Andean hillsides of Colombia, the humid and semi-humid tropical forest of Costa Rica, and the humid tropical forest of the Amazonia, Colombia.

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, C accumulation and C sinks. Research is conducted in Colombia and Costa Rica. Emphasis is given to poverty alleviation, as this research aims at demonstrating that enhancing C accumulation and protecting C sinks is economically attractive to farmers.

Project duration is 5 years (Dec1, 2001 - Nov30, 2006). Project cost is US $ 3,869.645,88, with a total contribution from The Netherlands Ministry of Development Cooperation, channelled through The Netherlands Embassy in Bogotá, Colombia, of US $ 1,552.885,88, representing 40.13 % of the project's total cost.

1.2 Project Main Goal, Objectives, Expected Products and Research Methodology

Project 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 ecosystems of the American Tropics. This main goal will be attained through conduction of scientific research and systematic observations in a range of pasture, agropastoral and silvopastoral systems in four ecosystems of the American Tropics vulnerable to climate change. Research aims at evaluating and documenting the capacity of these land management systems to increase land productivity, increase the farmer's economic benefit (alleviating poverty) and provide environmental services, in particular, increases in soil organic matter and carbon accumulation.

Ecosystems considered are:

(a) Eroded Andean hillsides of the semi-evergreen seasonal forest, Colombia (densely populated).
(b) Flat and mild-slope areas, of low altitude, of the humid tropical forest ecosystem, Amazonia, Colombia (zone of social conflict).
(c) Flat and mild-slope areas of the sub-humid tropical forest ecosystem, Pacific Coast of Costa Rica (densely populated)
(d) Flat and mild-slope areas of the humid tropical forest ecosystem, Atlantic Coast of Costa Rica (densely populated).

Project General Objective

Research aims at identifying improved and sustainable pasture and silvo-pastoral systems and conservation practices of native vegetation, that are able to recover degraded areas, provide a viable and economically attractive solution to the farmer (alleviating poverty), and offer environmental services, particularly increases in soil organic matter and carbon sequestration, and act as carbon sinks. Emphasis is given to poverty alleviation, as this research aims at demonstrating that recovering degraded areas with C-improved systems, provides environmental services and represents an economically attractive activity for farmers.

Specific Objectives

For each ecosystem subject of research, specific project objectives are:

1. Estimate soil and vegetation C stocks (ton of C /ha) of long-established pasture and silvopastoral system (of 10-20 years of age under commercial production, under grazing, in commercial farms) comparing them with degraded soil (negative reference system) and native forest, either fragmented, partially intervened, or non-intervened (positive reference system).

2. Estimate carbon sequestration rates (tons of C /ha/year) of newly-established improved pasture and silvopastoral systems on degraded lands.
3. Estimate the socio-economic benefit to farmers of establishing improved pasture, agropastoral or silvopastoral systems in degraded areas in their farms.
4. Identify, within each ecosystem considered, those land management systems (pasture, agropastoral, silvopastoral systems or natural regeneration of degraded pastures) that are economically attractive to the farmer (help alleviate poverty) and have a high capacity for carbon accumulation and carbon sinks.
5. Develop scientifically solid methodologies for the evaluation and estimation of carbon stocks and carbon sequestration rates in these tropical systems and ecosystems.
6. Extrapolate project results to similar environments in Tropical America.
7. Provide policy recommendations at local, national and international level, regarding policy decision to mitigate and adapt to the adverse effects of climate change, taking into account appropriate land use that provide environmental and socio-economic benefits to farmer population.

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 use systems.
- Policy recommendations for appropriate land use in these tropical ecosystems.
- Shared new knowledge with farmers, researchers and policy-makers invited to field days, training and divulgation 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 C sequestration in pasture, agropastoral and silvopastoral systems in the tropics.
- Identified regions in Tropical America where project results can be extrapolated.
- Identified land-use systems and sites for future possible CDM projects in the American Tropics.

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 ecosystems and comprises the four following research strategies:

A. Evaluation of a range of <u>long-established</u> pasture and silvo-pastoral systems of similar age within each 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 reference system) and native forest (positive reference system).

B. Evaluation of <u>newly-established</u> improved pasture and silvo-pastoral systems, established on degraded pasture areas, through small-plot replicated experiments, to quantify and compare after 4 years the level of C accumulation of these improved systems vs. the degraded pasture.
C. Socio-economic evaluation of costs and benefits to the farmer when establishing improved pasture and silvo-pastoral systems in degraded areas.
D. Model building to estimate C accumulation in silvopastoral systems.

2. *Chronogram of Activities (2001-2006)*

Activity	Year				
	1	2	3	4	5
Technical and administrative coordination activities					
1. Sign of Agreements with partner institutions, contract for project director and project members, and contract with farmers.	√				
2. Inter-institutional coordination meetings (1-2 per year)	√	√	√	√	√
3. Training courses for project personnel	√	√	√	√	√
4. Annual Plans preparation	√	√	√	√	√
5. Half-year technical and financial reports preparation	√	√	√	√	√
6. Final 5-year technical and financial reports preparation					√
Technical activities					
Implementation					
1. Characterization and first C-sampling of land use systems at each of the four ecosystems	√	√			
2. Second C-sampling of land use systems at each of the four ecosystems			√	√	
3. Laboratory analysis of soil and biomass samples	√	√	√	√	√
4. Statistical data analysis of soil characterization data and of first and second C-sampling data, from all ecosystems.		√	√	√	√
5. Initial C-evaluation before establishment of small-plot experiments in degraded pasture areas – all ecosystems	√	√			
6. Establishment of experiments in the degraded pasture areas		√			
7. Final C evaluation of improved options (experimental treatments) at the end of the experimental period.			√	√	
8. Evaluation, with farmers, of socio-economic benefits of establishing improved pasture and silvo-pastoral options	√	√	√	√	√
9. Statistical analysis of socio-economic data			√	√	
10. Construction and analysis of investment scenarios on improved systems, at farm level			√	√	
Scaling out					
11. Extrapolation Study with ISRIC, Wageningen, The Netherlands			√	√	
12. Digital maps and reporting on extrapolation study					√
Capacity building					
13. Support adoption by farmers (farmers field days and workshops)	√	√	√	√	√
14. Knowledge dissemination to policy-makers				√	√
15. Formation of Latin American researchers and students	√	√	√	√	√

3. Project Objectives vs. Achievements (2001-2006)

A summary of achievements related to each project objective is here presented. Detailed descrition of project results and interpretation is given in the final report by ecosystem, attached as **Annex 3** of this report, and in the Project Scientific Book presented as component of the present Final Technical Report.

Objective 1

Estimate soil and vegetation C stocks (ton of C /ha) of long-established pasture and silvopastoral systems

Achievments

Field evaluation of soil and vegetation C stocks (ton of C /ha) of long-established pasture and silvopastoral systems (of 10-20 years under commercial production) was carried-out in commercial farms under grazing. Estimated C-stocks from each land use system were compared with degraded soil (negative reference system) and native forest, either fragmented, partially intervened, or non-intervened (positive reference system). Field research was conducted during two C-sampling periods per ecosystem: 2002 and 2004 for Andean Hillsides, Colombia; 2003 and 2005 for Amazonia, Colombia; and 2002 and 2005 for Costa Rica ecosystems. Field research was completed on December 2005 for all ecosystems. Soil sample analysis was completed by March 2006; and statistical data analysis and interpretatiopn was done during the rest of 2006.

To achieve precise estimates, a sampling design that controlled the main sources of variation in C sequestration was used. Sources of variation were local site-specific conditions, such as altitude, temperature, precipitation, slope, and soil type; current land use; and history of use. Two spatial replicates/system were used with 12 sampling points/spatial replicate/system and 4 soil depths (0-10, 10-20, 20-40, and 40-100 cm). Apparent density, texture, pH, total C, oxidable C, total N, P and CIC were measured, using international analytical methods (USDA, 1996) at each sampling point/depth. Total C in fine roots, thick roots, and aerial biomass of pasture and trees was estimated using the methodology of CATIE and the University of Guelph (2000) to estimate the C in silvo-pastoral systems, multiplying the dry matter/hectare of each component by 0.46 (to estimate the C in pastures) and 0.48 (to estimate the C in roots and aerial biomass in silvo-pastoral systems). To statistically compare the soil C level among the different systems, C contents were corrected for apparent density and adjusted to a fixed soil weight using as reference value the sampling point of minimum weight in each ecosystem (Ellert *et al.*, 2002; Buurman *et al.*, 2004).

Tables 1-5 present the means of accumulation of C in the soil (adjusted to a fixed soil weight), C in pasture biomass, C in fine roots, and C in thick roots, trunks and leaves, together with the percentage that the C of each component represents of the C total of the system in each land use under study. Tables 1 and 2 present results for the Colombian Andean hillsides. Tables 3 and 4 those corresponding to the tropical rainforest of Colombia's Amazon region. Table 5 those corresponding to Costa Rica's subhumid tropical rainforest. The tables present global descriptive statistics (N, mean, CV (%), LSD$_{10}$), and the results of the statistical comparison of soil C among the different land use systems.

Table 1. Carbon in soil and biomass for each land use system.
Site 1: Dovio, Andean Hillsides, Colombia.[1]

Land use system	Total C in the soil (t/ha/1m-eq)	%	Total C pasture biomass (t/ha)	%	Total C in fine roots (t/ha)	%	Total C in thick roots, trunks, leaves (t/ha)	%	Total C in the system (t/ha)
Native forest	231 a[2]	75.7	-	-	4.6	1.5	69.7[3]	22.8	305.3
B. decumbens	147 b	97.2	0.9	0.6	3.3	2.2	-	-	151.2
Forage bank	131 c	86.1	-	-	4.3	2.8	16.9	11.1	152.2
Degraded pasture	136 c	96.8	0.5	0.4	3.9	2.8	-	-	140.4
N (sam points/ syst)	24		40		24		8		
Mean, CV (%), LSD$_{10}$	161,20, 18								

Table 2. Carbon in soil and biomass for each land use system.
Site 2: Dagua, Andean Hillsides, Colombia.[1]

Land use system	Total C in the soil (t/ha/1m-eq)	%	Total C pasture biomass (t/ha)	%	Total C in fine roots (t/ha)	%	Total C in thick roots, trunks, leaves (t/ha)	%	Total C in the system (t/ha)
Forest (40 years old)	186 a[2]	72.0	-	-	2.6	1.0	69.7[3]	27.0	258.3
Forest (15 years old)	155 ab	68.3	-	-	2.2	1.0	69.7[3]	30.7	226.9
Natural regeneration of degraded pasture	142 b	97.4	0.5	0.4	3.2	2.2	-	-	145.7
B. decumbens	136 b	93.7	0.8	0.6	8.3	5.7	-	-	145.1
Forage bank	90 c	81.2	-	-	2.5	2.2	18.4	16.6	110.9
Degraded soil	97 c	98.4	-	-	1.6	1.6	-	-	98.6
N (sam points/ syst)	24		40		24		8		
Mean, CV (%), LSD$_{10}$	135, 25, 30								

[1] Results 2002-2005, C Sequestration Project, The Netherlands Cooperation CO-010402, Internal Publication No. 14. June 2005.

[2] Means with different letters differ statistically, with an error probability of 0.10.

[3] Based on dry matter of aerial biomass for intervened Andean forests in Colombia (IDEAM, 2006) multiplied by 0.48 according to CATIE (2000)

Table 3. Total C in soil and biomass in long-established systems at 1m depth-equiv Flat Topography, Amazonia, Colombia

Land use system	Total Carbon (t/ha/1 m depth-eq)								
	Soil	%	Pasture biomass	%	Fine roots	%	Forest aerial biomass	%	Total C in the system
Native forest	107	58.5^3	-	-			75.9	41.5	182.9
B. humidicola	144	94.7	2.5	1.6	5.6	3.7	-	-	152.1
B. humidicola + leg	138	93.8	2.8	1.9	6.3	4.3	-	-	147.1
Natural reg of deg past	134	96.8	1.7	1.2	2.7	2.0	-	-	138.4
B. decumbens + leg	128	96.0	1.6	1.2	3.7	2.8	-	-	133.3
B. decumbens	124	97.3	1.4	1.1	2.1	1.6	-	-	127.5
N (samp points / syst)	27		45		27				
Mean, CV (%), LSD_{10}	129, 10, 5								

Table 4. Total C in soil and biomass in long-established systems at 1m equiv-depth Sloping topography, Amazonia, Colombia

Land use system	Total C(t/ha/1 m depth-eq)								
	Soil	%	Pasture biomass	%	Fine roots	%	Big roots, trunks and leaves	%	Total C in system
Native forest	181 a^2	58.5	-	-	-	-	128.5	41.5	309.5
B. decumbens + leg	172 b	97.8	1.2	0.7	2.7	1.5	-	-	175.9
B. humidicola	159 c	96.1	1.4	0.8	5.1	3.1	-	-	165.5
Nat. reg. of degr. pasture	129 d	96.8	1.2	0.9	3.0	2.3	-	-	133.2
N (samp points / syst)	27		45		27				
Mean, CV (%), $LSD_{.10}$	144, 11, 7								

Table 5. Carbon in soil and biomass for each land use system. Humid Tropical Forest ecosystem, Pocora, Costa Rica

Land use system	Total C in the soil (t/ha/1m-eq)	%	Total C pasture biomass (t/ha)	%	Total C in fine roots (t/ha)	%	Total C in thick roots, trunks, leaves (t/ha)	%	Total C in the system (t/ha)
B. brizantha + *A. pintoi*	181 a^2	98.4	1.5	0.8	1.5	0.8	-	-	184.0
I. ciliare grass	170 a	97.4	1.7	1.0	2.8	1.6	-	-	174.5
A. mangium + *A. pintoi*	165 b	90.0	1.0	0.6	4.4	2.4	12.9	7.0	183.3
B. brizantha	138 c	97.6	1.6	1.1	1.8	1.3	-	-	141.4
Native forest	134 c	60.1	-	-	4.0	1.8	85.1^3	38.1	223.1
Degraded pasture	95 d	94.6	1.6	1.6	3.8	3.8	-	-	100.4
N (samp points/ system)	24		40		24				
Mean, CV (%), LSD_{10}	150, 24, 14								

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[1] Results 2002-2005, C Sequestration Project, CO-010402, Internal Publication No. 14. June 2005.

[2] Means with different letters differ statistically, with an error probability of 0.10.

[3] Based on DM of forest aerial biomass (IDEAM, 2006) multiplied by 0.42 according to CATIE (2000)

Results

Data show that C accumulated in the soil represents from C in the total system: 61.7% in a native tropical forest, 90% in a silvo-pastoral system of *Acacia mangium* + *Arachis pintoi* (Table 5), and 95%-98% in pasture systems (Tables 1-4). The C accumulated in thick roots, trunks, and leaves in the silvo-pastoral system of *A. mangium* + *A. pintoi* accounts for 7% of the system's total (Table 5). The C accumulated in fine roots in pasture systems accounts for 3%-8% and the cumulative in pasture biomass, 0.5%-2.1% (Tables 1-4).

The data of the hillsides of Colombia's Andes (Tables 1, 2) suggest that at sites of higher altitude, lower temperature, steep slopes, and relatively more fertile soils, the forest shows the highest levels of C accumulated in the soil (231, 186, and 155 t/ha per 1m-eq at sites 1 and 2), these means being statistically higher than those of the improved *Brachiaria decumbens* pasture (147 and 136 t/ha per 1m-eq at sites 1 and 2), which, in turn, statistically surpassed those of a degraded pasture and a degraded soil (136 and 97 t/ha per 1m-eq at sites 1 and 2).

The data corresponding to the tropical rainforest of Colombia's Amazon region (Tables 3, 4) and to Costa Rica's subhumid tropical forest (Table 5) show a situation that differs from that of the Andean hillsides regarding levels of C accumulated in the soil. In the flat Amazon region, characterized by warm, humid lowlands with poor, extremely acid soils with a high nutrient recycling rate, the improved pasture systems of *Brachiaria humidicola* alone, *B. humidicola* + native legumes, *Brachiaria decumbens* alone and *B. decumbens* + native legumes show soil C levels (144, 138, 128, and 124 t/ha per 1m-eq) that are statistically higher than those of the native forest (107 t/ha per 1m-eq.) On the rolling slopes of the Amazon region, improved pasture systems show soil C levels (172 and 159 t/ha per 1m-eq) statistically higher than those found in a degraded pasture (129 t/ha per 1m-eq).

In Costa Rica's subhumid tropical forest (Table 5), located in the warm lowlands with a 6-month rainy season and a 6-month dry season, poor acid soils, the improved pasture and silvo-pastoral systems of *Brachiaria brizantha* + *Arachis pintoi*, *Ischaemum ciliare*, *Acacia mangium* + *A. pintoi*, and *B. brizantha* alone show levels of soil C accumulation (181, 170, 165, 138 t/ha per 1m-eq) statistically higher than those of the native forest (134 t/ha per 1m-eq) and to those of a degraded pasture (95 t/ha per 1m-eq).

Conclusions

C in the total system (C in soil + C in biomass) .- In terms of C in the total system, the native forest shows the highest level in all ecosystems. In all ecosystems, improved pasture and silvo-pastoral systems showed higher C-stocks than the degraded pasture.

C in the soil .- In terms of soil C-stocks, differences were observed between land use systems, which varied between ecosystems. In the humid tropical forest of Amazonia and Costa Rica, improved pasture and silvo-pastoral systems showed soil C-stocks comparable or even higher than the native forest

Objective 2

Estimate C-sequestration rates (t/ha/year) of improved pasture and silvopastoral systems newly-established on degraded lands.

Achievments

The estimation of carbon sequestration rates (expressed in tons of carbon/ha/year) of improved pasture and silvo-pastoral systems established on degraded pasture areas, was carried-out by establishing the improved systems in small-plot replicated experiments. Initial carbon stocks were evaluated in the degraded pasture before the establishment of the experiments. And final carbon stocks were evaluated at the end of the experimental period for each improved option. Carbon sequestration rates were estimated by difference.

Two replicated small-plot experiments per ecosystem were established in degraded pasture sites to monitor the changes in C accumulation in a 3.3-year period of recently improved systems compared to the initial degraded pasture. The treatments (improved systems) were: 1. natural regeneration of the degraded pasture; 2. improved grass in monoculture; 3. improved grass + legume pasture, and 4. forage bank for cut and carrying, with improved management. The initial degraded pasture was used as the reference treatment (control) in all experiments. Additionally, forage bank with local management was a second control in both the Andean Hillsides experiments and in the Amazonia flat topography experiment.

The Experimental Design used for all experiments was a Latin Square (4 x 4), with 4 blocks, 4 treatments/block established in such a way that every treatment was preceded by each other one the same number of times to avoid slope effect on treatment response. One or two control treatments were used depending on the experiment (degraded pasture and forage bank under local management).

The experiments were located in contrasting topography/landscape conditions of the ecosystems under study, one experiment per site, with different plot size, and different grass, legume and tree species depending on the ecosystem, as follows:

1. Andean Hillsides, Colombia: 2 experiments (located in Dovio and Dagua)
2. Humid tropical forest, Amazonia, Colombia: 2 experiments (located in flat and mild-slope topography areas)
3. Sub-humid tropical forest, Costa Rica: 1 exp. (located at Esparza, Pacific Coast).

Tables 6-9 show soil C-stock changes (increments or decrements) in improved pasture and silvo-pastoral systems established at each site with respect to the original degraded pasture, in a 3.3-year experimental period. Tables 6 and 7 show results from the two experiments established in Amazonia, in the flat topography area (table 6) and in the mild-slope topography area (table 7). Tables 8 and 9 show results of the experiments established in the Andean Hillsides, in Dagua (table 8) and Dovio (table 9).

Table 6. Increments in Soil C-stocks by improved systems established on degraded pasture. -Amazonia, Flat Topography Experiment, Santo Domingo Farm-

Initial C-sampling: Sept 2002 (on Degraded Pasture)
Final C-sampling: Dec 2005 (on each Improved System)
Experimental Period: 3.3 years

Depth (cm)	System	Soil C-stocks (t/ha/total C/ depth-eqv)	Soil C-stock increment (total carbon) vs. the initial Degraded Pasture			
			t/ha/depth-equv/3.3 yrs	**Sig prob Dunnet test**	**t/ha/depth -equv/yr**	**% inc/yr**
0-40	1. *B.* hybrid CIAT 4624 + *A. pintoi* 17434	91.2	16.9	***	5.1	6.9
	2. *B.* hybrid CIAT 4624 in monoculture	83.5	9.2	**	2.8	3.8
	3. Forage bank improved management	81.8	7.5	**	2.3	3.1
	4. Nat. regeneration deg pasture	81.1	6.8	**	2.1	2.8
	Degraded Pasture (reference system)	**74.3**	-	-	-	-
Mean and CV (%) of improved systems		82.4; 8.4%	10.1		3.1	
40-100	1. *B.* hybrid CIAT 4624 + *A. pintoi* 17434	68.1	6.8	***	2.1	3.3
	2. *B.* hybrid CIAT 4624 in monoculture	63.7	2.4	ns	0.7	1.2
	3. Forage bank improved management	65.0	3.7	ns	1.1	1.8
	4. Nat. regeneration deg pasture	65.0	3.7	ns	1.1	1.8
	Degraded Pasture (reference system)	**61.3**	-	-	-	-
Mean and CV (%) of improved systems		65.5; 8.2%	4.1		1.2	
0-100	1. *B.* hybrid CIAT 4624 + *A. pintoi* 17434	159.3	23.6	***	7.2	5.3
	2. *B.* hybrid CIAT 4624 in monoculture	147.3	11.6	**	3.5	2.6
	3. Forage bank improved management	146.8	11.2	**	3.4	2.5
	4. Nat. regeneration deg pasture	146.1	10.4	**	3.2	2.3
	Degraded Pasture (reference system)	**135.7**	-	-	-	-
Mean and CV (%) of improved systems		147.9; 6.0%	14.2		4.3	

Results

Soil carbon stock rates (t of total C /ha/year) of improved systems when established on degraded pasture areas.-

In the tropical humid forest ecosystem, Amazonia, Colombia, flat topography area, the best system was the grass + legume association, followed by the grass-alone system, the forage bank under improved management and finally, the natural regeneration of a degraded pasture. This ranking was the same for the upper soil layer (0-40 cm), the deeper soil layer (40-100 cm) and for the whole soil profile (0-100 cm). Soil C-seq rates, expressed in tons of total C/ha/year at 0-100 cm-equivalent, ranged from 3.2 to 7.2 and were the following:

Improved system	Soil C-seq rate (t/ha/year)
1. *B.* hybrid CIAT 4624 + *A. pintoi* 17434	7.2
2. *B.* hybrid CIAT 4624 in monoculture	3.5
3. Forage bank improved management	3.4
4. Nat. regeneration deg pasture	3.2
Degraded Pasture (reference system)	-

Table 7. Increment s in Soil C-stocks by improved system established on degraded pasture, Amazonia, Mild-slope Topography Experiment, Balcanes Farm

Initial C-sampling: Sept 2002 (on Degraded Pasture)
Final C-sampling: Dec 2005 (on each Improved System)
Experiment Period: 3.3 years

Depth (cm)	System	Soil C-stocks (t/ha/total C/ Depth-eqv)	Soil C-stock increment (total carbon) *vs.* the initial Degraded Pasture			
			t/ha/depth-equv/3.3 yrs	Sig prob Dunnet test	t/ha/depth-equv/year	% inc/yr
0-40	1. *B.* hybrid CIAT 4624 in monoculture	103.9	28.7	***	8.7	11.5
	2. Forage bank local management	94.8	19.5	***	5.9	7.9
	3. Nat. regeneration degraded pasture	92.7	17.4	***	5.3	7.0
	4. Forage bank improved management	85.5	10.2	**	3.1	4.1
	5. *B.* hybrid CIAT 4624 + *A. pintoi* 17434	80.5	5.2	ns	1.6	2.1
	Degraded Pasture (reference system)	**75.3**	-	-	-	-
Mean and CV (%) of improved systems		88.8; 10.0%	16.2		4.9	
40-100	1. *B.* hybrid CIAT 4624 in monoculture	56.5	-3.2	ns	-0.97	-1.6
	2. Forage bank local management	75.8	16.1	**	4.9	8.2
	3. Nat. regeneration degraded pasture	72.4	12.7	**	3.8	6.5
	4. Forage bank improved management	67.6	7.9	*	2.4	4.0
	5. *B.* hybrid CIAT 4624 + *A. pintoi* 17434	60.5	0.8	ns	0.2	0.4
	Degraded Pasture (reference system)	**59.6**	-	-	-	-
Mean and CV (%) of improved systems		65.4; 12.0%	6.9		2.1	
0-100	1. *B.* hybrid CIAT 4624 in monoculture	160.4	25.5	***	7.7	5.7
	2. Forage bank local management	170.6	35.7	***	10.8	8.0
	3. Nat. regeneration degraded pasture	165.0	30.1	***	9.1	6.8
	4. Forage bank improved management	153.1	18.2	**	5.5	4.1
	5. *B.* hybrid CIAT 4624 + *A. pintoi* 17434	141.0	6.1	ns	1.8	1.4
	Degraded Pasture (reference system)	**134.9**	-	-	-	-
Mean and CV (%) of improved systems		154.2; 8.5%	23.1		7.0	

Results

In the tropical humid forest ecosystem, Amazonia, Colombia, mild-slope topography area, the best system in the top layer (0-40 cm) was the grass alone. However, in the deeper layer and in the whole soil profile the ranking changed, showing that forage bank systems and natural regeneration of a degraded pasture presented the highest carbon sequestration rates. This is probably due to the long roots of forage bank species and regenerating weeds. Soil C-seq rates expressed in tons of total C/ha/year at 0-100 cm-equivalent ranged from 1.8 to 10.8 and were the following:

Improved system	Soil C-seq rate (t/ha/year)
1. Forage bank local management	10.8
2. Nat. regeneration degraded pasture	9.1
3. *B.* hybrid CIAT 4624 in monoculture	7.7
4. Forage bank improved management	5.5
5. *B.* hybrid CIAT 4624 + *A. pintoi* 17434	1.8
Degraded Pasture (reference system)	-

Table 8. Increment s in Soil C-stocks by improved systems established on degraded pasture. – Andean Hillsides, Dagua Experiment -

Initial C-sampling: May 2002 (on Degraded Pasture)
Final C-sampling: Oct 2005 (on each Improved System)
Experimental Period: 3.4 years

Depth (cm)	System	Soil C-stocks (t/ha/total C/ Depth-eqv)	Soil C-stock increment (total carbon) *vs.* the initial Degraded Pasture			
			t/ha/depth-equv/3.4 yrs	Sig prob Dunnet test	t/ha/depth-equv/year	% inc/yr
0-40	1. *Brachiaria* ("Mulato")	127.3	21.6	Ns	6.4	6.0
	2. Nat. regeneration degraded pasture	123.6	17.9	Ns	5.3	5.0
	3. *B.* Mulato + *A. pintoi*	117.2	11.6	Ns	3.4	3.2
	4. Forage bank local management	116.2	10.6	Ns	3.1	2.9
	5. Forage bank improved management	107.2	1.6	Ns	0.5	0.4
	Degraded Pasture (reference system)	**105.7**	-	-	-	-
Mean and CV (%) of improved systems		116.2; 57.4%	12.7		3.7	
40-100	1. *Brachiaria* ("Mulato")	59.8	16.5	***	4.9	11.2
	2. Nat. regeneration degraded pasture	52.9	9.6	Ns	2.8	6.5
	3. *B.* Mulato + *A. pintoi*	54.8	11.5	Ns	3.4	7.8
	4. Forage bank local management	47.9	4.6	Ns	1.4	3.1
	5. Forage bank improved management	47.3	3.9	Ns	1.1	2.6
	Degraded Pasture (reference system)	**43.3**	-	-	-	-
Mean and CV (%) of improved systems		51.0; 26.2%	9.2		2.7	
0-100	1. *Brachiaria* ("Mulato")	187.1	38.1	***	11.2	7.5
	2. Nat. regeneration degraded pasture	176.5	27.5	***	8.1	5.4
	3. *B.* Mulato + *A. pintoi*	172.1	23.1	Ns	6.8	4.6
	4. Forage bank local management	164.1	15.1	Ns	4.4	3.0
	5. Forage bank improved management	154.5	5.6	Ns	1.6	1.1
	Degraded Pasture (reference system)	**148.9**	-	-	-	-
Mean and CV (%) of improved systems		167.2; 15.5%	21.9		6.4	

Results

In the Andean Hillsides ecosystem, Dagua, Colombia, the grass-alone system, *Brachiaria* hybrid "Mulato", showed the highest and statistically significant increase in soil carbon stocks when established on a degraded pasture area, with a C-sequestration rate of 11.2 tons of total C /ha/year at 0-100 cm-equivalent. The second best system was the natural regeneration of a degraded pasture, with a rate of 8.1 tons of total C /ha/year at 0-100 cm-equiv.

None of the other improved systems showed a statistically sigifficant increase in soil carbon stocks vs the original degraded pasture. This is due to the very high soil variabilisty in this site, expressed in the high CV (%) of soil carbon stocks (57.4% for 0-40 cm; 26.2% for 40-100 cm, while corresponding CV's in Amazonia experiments were of 8.4.% and 8.2% for flat topography; and of 10.0% and 12.0% for mild-slope topography respectively).

Table 9. Increments in Soil C-stocks by improved systems established on degraded pasture. – Andean Hillsides, Dovio Experiment -

Initial C-sampl: April 2002 (on Degr. Pasture); Final C-sampl: Sep 2005 (on each Improved System)
Experimental Period: 3.4 years

Depth (cm)	System	Soil C-stocks (t/ha/total C/ depth-eqv)	Soil C-stock increment (total carbon) *vs.* the initial Degraded Pasture			
			t/ha/depth-equv/3.4 yrs	Sig prob Dunnet test	t/ha/depth-equv/year	% inc/yr
0-40	1. *Brachiaria* "Mulato" + *A . pintoi*	123.5	12.4	*	3.65	3.3
	2. Nat. regeneration degraded pasture	110.8	-0.3	ns	-0.09	-0.09
	3. Forage bank local management	108.2	-2.9	ns	-0.90	-0.77
	4. *Brachiaria* ("Mulato")	106.6	-4.5	ns	-1.30	-1.18
	5. Forage bank improved management	104.9	-6.2	ns	-1.82	-1.65
	Degraded Pasture (reference system)	**111.1**	-	-	-	-
Mean and CV (%) of improved systems		111.8; 16.5%	-0.3		-0.09	
40-100	1. *Brachiaria* "Mulato" + *A . pintoi*	65.0	11.3	*	3.3	6.2
	2. Nat. regeneration degraded pasture	42.5	-11.2	ns	-3.3	-6.1
	3. Forage bank local management	60.7	7.0	ns	2.1	3.8
	4. *Brachiaria* ("Mulato")	47.0	-6.8	ns	-2.0	-3.7
	5. Forage bank improved management	61.5	7.7	ns	2.3	4.2
	Degraded Pasture (reference system)	**53.7**	-	-	-	-
Mean and CV (%) of improved systems		53.9; 24.9%	1.6		0.48	
0-100	1. *Brachiaria* "Mulato" + *A . pintoi*	188.5	23.7	*	7.0	4.2
	2. Nat. regeneration degraded pasture	153.3	-11.5	ns	-3.4	-2.1
	3. Forage bank local management	169.0	4.1	ns	1.2	0.7
	4. *Brachiaria* ("Mulato")	153.6	-11.2	ns	-3.3	-2.0
	5. Forage bank improved management	166.3	1.5	ns	0.4	0.3
	Degraded Pasture (reference system)	**164.8**	-	-	-	-
Mean and CV (%) of improved systems		165.7; 15.9%	1.3		0.38	

Results

In Dovio site, Andean Hillsides ecosystem, Colombia, an even higher soil variability than in Dagua site was present. CV of soil C-stocks for 0-40 cm was 63.1% and for 40-100 cm was 26.9%. For this reason, complemented with results of data quality analysis (P. Buurman), the exclusion of heterogeneous sampling points (soil pits) was done in order to carry-out the statistical analysis. The initial experimental design had 4 blocks, 5 improved systems (treatments) per block, and 3 soil pits/treat/block, that is, 12 soil pits/treat were sampled, with a total of 60 sampling points. Sampling points retained/treatment (after data quality analysis) were as follows:

1. *B.* hybrid "Mulato": all 4 Blocks	12
2. *B.* hybrid "Mulato" + *Arachis pintoi*: all 4 Blocks	12
3. Forage Bank - improved managmnt: (Blocks 3,4)	6
4. Forage Bank - local managmnt: (Blocks 1,4)	6
5. Natural Regeneration Degraded Pasture: alll 4 Blocks	12
Total No. Sampling points retained, from the 60 original	51

After eliminating heterogeneous sampling points, CV's reduced from 63.1% to 16.5% (0-40 cm) and from 26.9% to 24.9% (40-100 cm). However only the *B.* hybrid "Mulato" + *Arachis pintoi* showed a statistically significant increase in soil carbon stocks with respect to the original degraded pasture, with a C-seq rate of 7.0 tons of total C /ha/yr/0-100 cm-equiv.

Objective 3

Estimate the socio-economic benefit to farmers of establishing improved pasture, and silvopastoral systems in degraded areas

Achievments

Objectives of the socio-economic research.-

Given the growing concerns with global warming and the social and economic importance of livestock in Latin America it is imperative to identify livestock production systems that are able to capture carbon (C) and are at the same time financially attractive to farmers.

Questions addressed by the socio-economic research are: (i) how much C can different livestock systems in the ecosystems covered by this project sequester? (ii) are those land use systems financially viable vis-à-vis current land use practices?, (iii) what is the potential financial effect of a payment for C sequestration on farm income and on the financial feasibility of land use systems that sequester C? In this regard, the focus of the socio-economic research is to identify land use systems sequestering C that are financially viable. In particular, the aim of this research is to assess if implementing land use practices that enhance C accumulation and protect C sinks is financially attractive to farmers. To that end, the objectives of the socio-economic research are:

- To characterize the socio-economic conditions of farms participating in the project;
- To describe land use on farms included in the project;
- To define establishment costs and operating expenditures of different C sequestering livestock systems, as well as their production and revenue levels;
- To explore the financial feasibility of investing in different C sequestering livestock systems;
- To develop models on the financial effect that a potential payment for C storage may have as an incentive to incorporate C sequestering livestock systems on farms;
- To provide policy guidelines to promote the implementation of C sequestering livestock systems on farms in Tropical America.

The socio-economic questions posed by the present project require a conceptual framework based on a systems approach. The conceptual framework is developed to establish the relations between the farms and its external context in order to help identify relevant characteristics of the system under study that may influence the implementation of C sequestering livestock systems. Accordingly, it provides conceptual unity to the study and allows to link socio-economic results obtained at different levels.

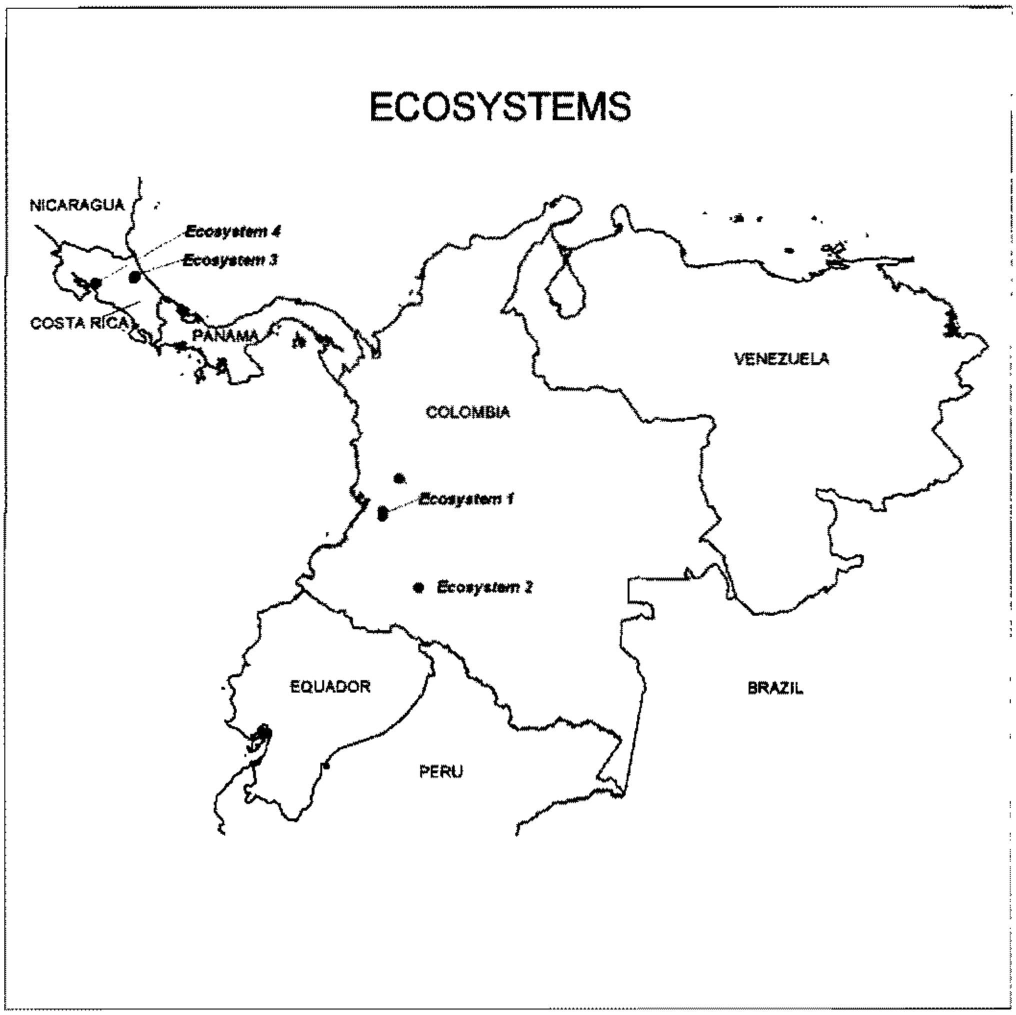

Figure 1. Location of CSEQ research sites.

The maps are derived from of an analysis of the Soil and Terrain Database for Latin America and the Caribbean - SOTERLAC (Dijkshoorn *et al.* 2005; FAO *et al.* 1998), the SRTM90 digital elevation model (USGS 2003) and the Global Agro-Ecological Zones Map - AEZ (FAO-IIASA 2000) for the region. The extrapolation for the Amazon ecosystem mentioned under (2), was based on the analysis of AEZ and SOTER only, but a subdivision on slopes (breakpoint 5%) was made to distinguish foothills from the flat areas.

1. INTRODUCTION

Terms of Agreement between the Carbon Sequestration Project (CSEQ) – a research Network for the Evaluation of Carbon Sequestration Capacity of Pasture, Agropastoral and Silvopastoral Systems in the American Tropical Forest Ecosystem – and ISRIC – World Soil Information were signed on April 28th 2005, to establish collaboration in support of producing an extrapolation study for the four ecosystems of CSEQ. The project period was from 01-11-2005 until 28-2-2006.

The ecosystems considered in CSEQ's research sites are:

1. *Tropical Andean hillsides* in Colombia,
2. *Humid tropical forest, Amazonia* in Colombia,
3. *Humid tropical forest* at the Atlantic coast of Costa Rica,
4. *Sub-humid tropical forest* at the Pacific coast of Costa Rica

The location of the CSEQ research sites is shown in Figure 1.

Similar environmental conditions as found in the four ecosystems were to be identified in:

(a) Colombia and the neighbouring countries of Ecuador, Peru and Bolivia for ecosystem 1
(b) Colombia and the neighbouring Amazonian countries of Peru, Brazil, Bolivia and Ecuador for ecosystem 2
(c) Costa Rica and the neighbouring countries of Panama, Nicaragua, Honduras, El Salvador and Guatemala for ecosystems 3 and 4.

The deliverables were specified as:

Three digital maps with the paper copies at scale 1:5 M (one per ecosystem) and accompanying databases. These show, for each of the ecosystems, areas having similar conditions (length of growing period, altitude, slope and soil conditions) as found in the corresponding research sites of CSEQ.

Similar areas as the research sites in the Humid Tropical Forest in Costa Rica cover 750 km^2 in the country itself and in neighbouring Nicaragua and Guatemala.

The Sub-humid Tropical Forest ecosystem of Costa Rica has equivalent areas in the country itself and in Panama and Nicaragua, totalling 1,300 km^2.

Keywords: carbon sequestration, pasture systems, tropical forest, SOTER database, Length of Growing Period, Digital Elevation Model.

SUMMARY

This document presents the results of an extrapolation study for the Carbon Sequestration Project (CSEQ) – a research Network for the Evaluation of Carbon Sequestration Capacity of Pasture, Agropastoral and Silvopastoral Systems in the American Tropical Forest Ecosystem.

Research ecosystems of CSEQ are:
- Andean Hillsides, Colombia
- Humid Tropical Forest, Amazonia, Colombia
- Humid Tropical Forest, Atlantic Coast, Costa Rica
- Sub-humid Tropical Forest, Pacific Coast, Costa Rica

Similarity was based on climatic parameters, topography (elevation and slope) and soil conditions. The Length of Growing Period (LGP) is used to characterize the climate conditions of the research sites. A Digital Elevation Model (DEM) with a resolution of 90 m was used to define elevation and slope conditions, while soil characterization originated from the Soil and Terrain Database of Latin America and the Caribbean (SOTERLAC). Available (sub)continental data allowed only for a low resolution of the maps produced (scale 1:5M).

Results are presented as maps and in tabular format.

Some 7,000 km^2 and 3,000 km^2 of areas similar to the Andean Hillsides ecosystem, as represented by the two experimental sites, occur in Colombia, Peru and Ecuador.

The Humid Tropical Forest ecosystem, represented by the Amazonia sites in Colombia, extends to 288,000 km^2 of similar areas with *Haplic Acrisols* and 80,000 km^2 of *Haplic Ferralsols* covering large parts of the Amazon basin in Colombia, Brazil and Peru.

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Report 2006/01

Extrapolation Study for the Carbon Sequestration Project of Pasture Systems in the American Tropical Forest Ecosystem

Vincent van Engelen
Jan Huting

(February 2006)

ISRIC World Soil Information

Annex 2

ISRIC Extrapolation Study

Training and Seminars

Over the five year period the project contributed to training several experts in the region

1. Postgraduate. Two Msc thesis was completed within the framework of the project. One thesis measured C sequestered in the pasture and silvopastoral system and the other evaluated socio-economic impacts of different land use systems. One PhD thesis is in the final process which evaluated variability of C sequestered in the sub-humid and humid ecosystems of Costa Rica.
2. Training courses. The following training courses were offered.

a) Carbon sequestration in pasture and silvopastoral systems. 20 participants.
b) Methodology for quantification of C in pasture and silvopastoral systems 25 participants.
c) Model for balance of greenhouse gases in livestock farms. 15 participants.
d) Methodologies for developing farm plans with good farming practices. 16 participants.

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WRI, 2000. World Resources 2000–2001: People and ecosystems: The fraying web of life. United Nations Development Programme, United Nations Environment Programme, World Bank, World Resources Institute, Washington DC.

model. Secondary information from the literature was also used for the CO_2 fix model (Annex 3). This model is a useful tool for policy makers to make decisions of the hot spots for C sequestration in landscape dominated with cattle and what are the land use systems that incentives should be provided to promote adoption of the land use systems. The CO_2 fix models generated results on increments of C that were comparable to what was estimated in the newly established experiments.

2. In Costa Rica, the project worked with the Ministry of Environment and FONAFIFO (national fund for payment of environmental services in forest and agroforestry systems) to identify the critical areas for payment of CO_2 sequestration in the context of CDM (see Figure 1) and in this respect a large percentage of the area earmarked for CDM coincides with landscapes dominated with cattle and pastures. The results of the project were disseminated to policy makers who make decisions on CDM and payment of environmental services.
3. Index for payment of environmental services. CATIE has been collaborating with FONAFIFO for developing an index for PES which includes C sequestration and the results of the C-network project was used to develop this index.
4. In Costa Rica, FONAFIFO will implement a project on payment for environmental services in agricultural landscape and CATIE will support FONAFIFO for monitoring and evaluation of C- sequestered in different systems utilising the methodology developed by the C- network project.
5. The results of the project are also disseminated in the Central American region including the CCAD.

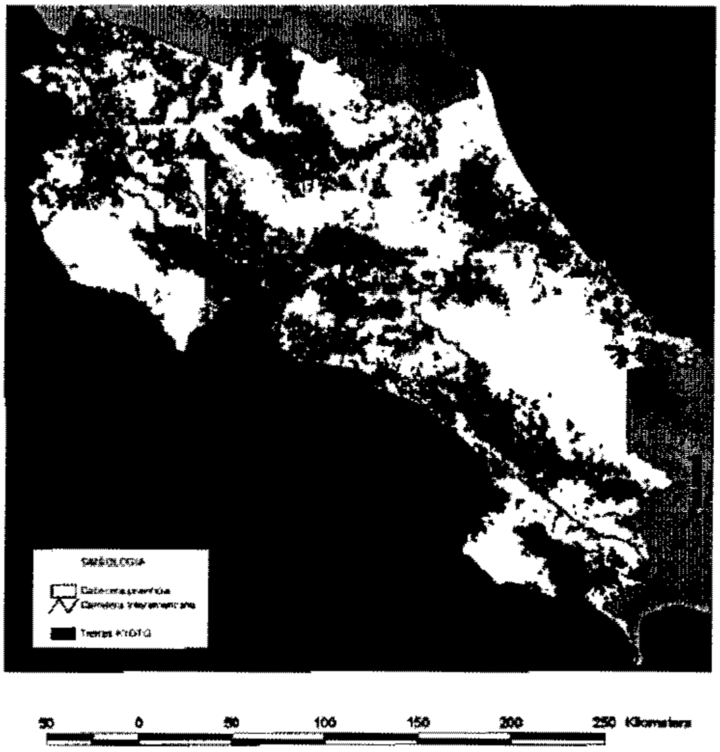

Figure 1. Land uses identified as critical areas for payment of CO_2 sequestration in the context of Clean Development Mechanism (CDM) in Costa Rica.

with trees to estimate biomass and C fixed in tree biomass. Sampling was done for root biomass and in Annex 1 is shown the methodologies used for different measurements. The results of the experiment are presented in Annex 2. The main findings were the following:

1. The amount of C fixed in the improved pastures was significantly higher than that of the fodder bank with *C. argentea*. C fixation was 4.1, 3.5, 2.0, 3.7 and 2.0 Mg/ha/yr in *B. brizantha*+ A. pintoi, *B.brizantha*, *Cratylia argentea* fodder bank and H. rufa, respectively. The amount of C fixed was not different between the pastures types though B. brizantha+A.pintoi mixture had slightly higher amount of C fixed. The amount of C fixed in the natural regeneration plots was 2.0 Mg/ha/yr.

2. Annual amounts of C produced in biomass of pastures and the fodder banks were significantly different between land use types. It was more than doubled that produced in the fodder bank with *C. argentea*. The amounts of carbon in biomass were 10.11 for *B. brizantha + A. pintoi*, 9.85 for *B. brizantha*, 8.79 for *H. rufa* and 3.73 for *Cratylia argentea* fodder bank.
3. The amount of C in fine root biomass was also different between treatments such that grasses had higher amounts of C- sequestered in root biomass at 0-40 and 40-100 com depth compared to *C. argentea* fodder bank. The values for the 0-40 cm depth were 4,45, 3.97, 1.58 and 2.21 for B. brizantha, *B. brizantha+A. pintoi*, *Cratylia argentea* fodder bank and *H. rufa*, respectively; and the corresponding values for the 40-100 cm depth were 1.55, 0.93, 0.45 and 1.38. The *B. brizantha* plot had more than 25% of C in fine roots in the 40- 100 cm depth indicating that this species is capable of depositing C in deep soil layers. The plot with secondary succession or natural regeneration had 4.2 Mg C/ha in fine root biomass in the 0-100cm depth.

Socio-economic evaluation of the establishment of improved pasture and silvo-pastoral systems in degraded pasture farms

Results and interpretation are presented in the project scientific book entitled "Carbon Sequestration in Tropical Grassland Ecosystems", chapter 6.

Extrapolation of project results to similar areas in Tropical America

Results are presented in detail in the present Final Technical Report, under numeral 2: "Objectives *vs.* Achievements".

Policy recommendations in terms of appropriate land use in the two Cost Rica ecosystems, humid and sub-humid tropical forest

1. The project worked to adapt the CO_2-fix model that was developed for forest systems for quantifying C in pasture and silvopastoral systems. The data from the long term and newly established experiments were used to develop the parameters for the

sequestered in biomass was 0.24, 1.3, 1.21, 0.99, 0.65 respectively for *A. mangium+A. pintoi*, *B. brizantha+A. pintoi*, *B. brizantha*, *I. ciliare* and degraded pasture.

3. In the humid tropics, C sequestered in the soil of forest was relatively low compared to that in the improved pasture and SPS, but C sequestered in above ground biomass of trees was somewhat higher than that sequestered in the soil, total C it was 141.32 Mg ha for soil and 174.2 Mg ha for above ground biomass of trees
4. In the sub-humid zone of Esparza, the degraded pastures were invaded with weeds and in these systems there are large amounts of C cycled in the system and for this reason we named this land use as weedy pastures. Total amount of C stored in the soil was higher for secondary forest and forest plantations and H. rufa pastures compared to the B. decumbens and silvopastoral system. The values for total C in soil were 154.84 for weedy pasture, 220.92 for *H. rufa*, 109.56 for *B. decumbens* pasture, 119.95 for silvopastoral system, 124.26 for Fodder bank-*Cratylia argentea*, 222.78 for teak forest plantation, 225.99 for secondary forest, and 94.44 for Native forest. Stable soil C was not affected by land use.
5. The amount of C stored in the native forest in Esparza was relatively low compared to other pasture use but a relatively large amount of C was sequestered in the biomass of trees of native forest. The values were 94.44 Mg total C ha^{-1} in soil and 99.9 for biomass.
6. The amount of C sequestered in available biomass was different between systems were 0.86 for *B. decumbens* pasture, 0.76 for *H. rufa*, 0.52 for weedy pasture and 0.77 Mg C $ha^{-1}$for silvopastoral system. Dry season yields were lower than that of rainy season

Evaluate carbon stock changes when improved pasture and silvo-pastoral systems are newly-established on degraded pasture land, through small-plot experiments.

The amount of C fixed in pasture and silvopastoral systems is affected by climate, topography, soil, vegetation and management factors including the use of fertilizers and grazing regimes. In the sub-humid zone of Esparza, cattle farmers have been adoption improved grasses and legume mixtures and the use of fodder banks with trees and shrubs for feeding cattle in the dry season. The amount of carbon fixed in these systems may be different because of the differences in biomass production between the species and other factors. To evaluate the potential of improved pasture and sivopastoral systems to fix carbon, an experiment was set up in a degraded pasture site in 2003. The treatments were: *Brachiaria brizantha* in monoculture, *B. brizantha* + *Arachis pintoi*, *Hyparrheinia rufa* and Cratylia argentea, a shrub legume. The area in which the experiment was planted was a sloping area (> 30%) and a Latin Square design was used for the experiment with each plot 100 m2. In addition to these treatments, the degraded pasture was rested for secondary succession to determine the rate of C fixation in time. The grasses were harvested 4 months after establishment and thereafter every 35 days and the fodder bank was harvested 6 months from the time of establishment and thereafter every 4 months. Data was collected on soil carbon and physical and fertility parameters, dry matter yields of the pasture and botanical composition. In the plots with trees, inventory was made

The amount of C sequestered in pasture and silvopastoral systems varies between land use systems depending on the climate, vegetation, soil, topography and management factors. In pasture and sylvopastoral systems a large amount of C is sequestered in the soil and depending on the associated grass species and trees, the amount of C (including stable C) deposited in deep soil layers (40 – 100 cm) may vary. The integration of trees in pastures may also contribute to increased C stocks above ground and more stable C may be sequestered in the tree trunk. In order to determine the amount of C sequestered (above and below ground), in different land uses a study was conducted in the sub-humid zone of the Pacific region of Costa Rica in Esparza and in the humid zone of Pocora in Costa Rica. The land uses studied are shown in table 1.

Table 1. Land-use systems evaluated. Humid and sub-humid tropical zone of Costa Rica.

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

The methodology used for sampling for soil and vegetation is shown in **Annex 1**. The results on carbon stocks below and above ground are shown in **Annex 2** . The main findings of the long term experiment were:

1. There were large variation of the amount of C sequestered in soils of the two ecosystems which may be explained to soil characteristics and differences in land use patterns over time especially in Esparza where burning was frequently practiced and results in increased amount of Charcoal as stable C stocks.
2. In the humid tropics of Pocora, the amount of C sequestered in improved and or naturalised pasture and silvopastoral systems were significantly higher than that of the degraded pastures. Total C for degraded pasture, *I. ciliare*, *B. brizantha*, *B. brizantha*+ *A. pintoi*, *A. mangium*+*A. pintoi* and Forest were 107.88, 254.2, 153.02, 186.78, 160.69 and 141.32, respectively. Stable C stocks were higher for ratana (I. cilare) and *B. brizantha* pastures and the silvopastoral system with A. mangium. The amount of C sequestered in biomass of pastures was significantly higher than that of *A. pintoi* in the silvopastoral systems, and C sequestered in biomass of pastures showed a decreasing trend in time. The amount of C

Final Report on Research Activities in The Costa Rican Ecosystems

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Background

In Central America, pastures now cover more than nine million ha (about 30% of the total land area), half of which are estimated to be degraded (Szott et al., 2000). During the 1970s and early 1980s, high international demand and prices for cattle-based products, combined with rapidly increasing populations, incorrect land settlement policies and schemes, easy credit and subsidies for ranching, inappropriate land tenure regulations and infrastructure expansion at national levels, led to a rapid and large-scale expansion of the cattle industry in Central America. Over the past decade this pasture area expanded at a annual rate of four to nine percent, mostly at the expense of tropical forest (Szott, 2000, WRI 2000). There were also large geographical shifts of cattle to humid rainforest areas with fragile soils, often on steep slopes; more than 30% of cattle farms and 40% of pastures in the region are found on humid and sub-humid hillsides and pasture degradation is especially evident in these sites (Szott, 2000). The result was a massive conversion of forests to pastures, but not the sustainable management of pasture or the use of more suitable alternatives for deforested lands.

Research conducted by CIAT, CATIE and CIPAV in Latin America indicate that the implementation of improved grass-legume and silvopastoral pastures are involved in increased productivity and economic efficiency of farms while contributing to generation of environmental services including carbon sequestration and conservation of water resources. Recently there has been interest in developing markets for carbon in agricultural systems and in this respect cattle farmers can benefit from carbon produced in sustainable pasture and silvopastoral systems. In this respect, over the past five years CATIE has been collaborating with CIAT, CIPAV and the Amazon University of Colombia to conduct research to quantify the impacts of improved pasture and silvopastoral systems in C sequestration and to develop policy recommendations for designing incentive schemes for compensating farmers for carbon. This document represents the final report on the achievements of the project in Costa Rica which is reported according to each objective below:

Objectives:

Evaluate carbon stocks in long-established pasture and silvo-pastoral systems, comparing them with native forest (positive reference system) and degraded pasture (negative reference system).

Final Report: Semi-humid and Humid Tropical Forest, Costa Rica

Once the project finished, field days were held to discuss results and construct strategies to achieve more efficient production systems in biological, social, and economic terms.

Academic activities

These included:

1. Training. Knowledge facilitating technology transfer was expanded through the teaching of short courses to enhance different areas related to methodologies for evaluating carbon and valuing environmental services.
2. The experience of participation in an international research network on such an innovative subject as climate change placed the institution in the vanguard of scientific knowledge.
3. Participation in an international research project became an important input within the institutional achievements presented for academic peer review as part of the procedures for obtaining accreditation of undergraduate academic programs.
4. Publication of articles in scientific journals.
5. Participation in the writing of a scientific book that compiles the results of 5 years of research.

Personnel training—undergraduate and graduate

Education of four (4) undergraduate students, two of whom have graduated, one with a meritorious thesis, and the other two awaiting graduation in Agroecological Engineering.

Some of the socioeconomic results provided support for the writing up of a doctorate dissertation in Sciences by a university lecturer.

Exchange of scientists with other research institutions in the world

Participation at six (6) international meetings at which the project's advances were presented and an exchange of knowledge and experiences was carried out with other participants.

In the tropical humid rainforest ecosystem, under conditions of high precipitation and temperatures, pasture systems have potential for capturing carbon. Results indicate an orientation towards increasing the supply of environmental services by reclaiming degraded areas in the Amazon Region through a range of possibilities that include introduced pastures under monoculture and in association with herbaceous legumes, through agroforestry systems (mixed protein banks and silvopastoral/native-pasture grazing systems), to carbon capture under native forests.

The Amazon Region is an area that generates polemics. It therefore needs an integrated approach to environmental and social policy-making in the national and world arenas. Hence, all possible policy management must be made to present the results of this project in terms of systems of optimal land use from the environmental viewpoint. The systems should also be shown to comply with the policies outlined by the CDM and, in social and economic terms, to contribute to food security, thus alleviating poverty.

Emphasis must be given to the importance of presenting the humid rainforests of the Amazon Region as natural ecosystems that capture carbon, vital for the clean development markets. A condition should also be included to permit the promotion of "Prevented Deforestation" as a tool to pay for environmental services.

The change towards land-use systems that are more efficient in producing forages and environmental services should be promoted in degraded areas (soils and pastures) that capture carbon inefficiently, thereby generating income and employment, and offering possibilities of food security for rural families. Under no circumstances should it be promoted in areas of native forests.

The advances in knowledge on carbon capture form a basic complement to show results, achieved by implementing land use systems (introduced improved pastures and silvopastoral systems), in terms of major production and economic indices. These can be complemented by strategies for organic markets for those agricultural products of the Amazon Region obtained under environmental conditions that are propitious for the ecosystem and which alleviate poverty.

SECOND PART:

THE PROJECT'S CONTRIBUTIONS TO INSTITUTIONAL BUILDING

Social projection activities

During the project's execution, an ongoing exchange with the region's farmers existed, permitting the strengthening of relationships and facilitating the exchange of knowledge. To attain objectives, participatory workshops were held to share the knowledge needed to use measurement tools.

The economic indicators of the two types of farms (details in Section 5.5, Chapter 5) showed that between 35% and 88% of total costs for type I farms were dedicated to livestock and related activities such as paddock management, health control, and labor. For type II farms, 78% of inputs were dedicated to livestock management, and the rest to pasture support.

Type I farms were characteristically managed through family labor and presented a gross margin of almost US$130/ha in those exploitations that managed grazing with improved grasses in association with herbaceous legumes and in addition supplemented with forages produced by protein and energy banks. Those farms that managed their cows on degraded pastures presented a gross margin of about $10/ha. The gross margin attained by type II farms was about $129/ha.

Models of financial evaluation of changes in land use with contributions from carbon capture showed that the net income per hectare would increase by US$108.37/ha on converting 1 ha of poorly managed natural pasture to improved pasture in association with legumes. The cost that the small farmer would pay to carry out the change was about $435, but the amount that would be disbursed in the first year would only be $383 because the first 6 months would be needed to establish the pasture for use. Receiving $108/ha every year on top of what would have been received if the farm had been kept under natural pastures signifies that, after 4 years, the investment made in the land-use change would be paid off. When the financial model was adjusted to change from natural pastures to improved pastures plus forage bank, the internal rate of return was 34.8% and the period of repayment 3.5 years.

Overall, this evaluation shows that farm income would pay production costs and receive an additional payment for environmental services for carrying out land-use changes from degraded systems to diversified ones that conserve biodiversity and soils, and fix carbon. The rural populations' social and economic situation would improve, and higher food production under more sustainable conditions would be possible.

Objective 3: To make technological and management recommendations that are appropriate to different land-use systems, with a view to making them economically attractive to farmers and benefiting the environment.

The recommendations are as follows:

Beyond the environmental achievement of capturing carbon in the different land-use systems evaluated (with reference to the negative control of degraded pasture), the project's results permitted the analysis of technological alternatives to improve degraded soils in the Colombian Amazon. Such alternatives would go hand-in-hand with greater productivity, social stability, and greater economic yield, thus alleviating the rural population's poverty.

Section 5.3 in Chapter 5 describes the results for carbon capture under four established land uses, managed and evaluated as experiments, in flat and sloping topographies. On the flat, evaluations of capture in soils at 1 m deep show that the association of *B. mulato* II with *A. pintoi* had the highest average carbon accumulation at 174.3 t/ha. It showed a significant difference with the negative control (degraded pasture) of 31.2 t/ha, and represented 21.8% of the cumulative total. All the experiments showed significant differences with the negative control.

On the sloping field, in addition to the experiments evaluated on the flat field, a forage bank treatment was assessed under local management (i.e., according to traditional farmer management). In this topography, at a soil depth of 1 m, the highest accumulation was achieved by the treatment *B. mulato* II under monoculture, with 191.5 t/ha; followed by the forage bank under local management, with 181.1 t/ha; natural regeneration, with 175.3 t/ha; and the forage bank under improved management, with 168.2 t/ha. All these treatments showed significant differences with the negative control. The only treatment that did not report significant differences was the association of *B. mulato* II and *A. pintoi.*

The net carbon accumulation in the soil over 3 years of evaluative experiments in the Amazon Region, assessed in tons per hectare of fixed mass to 1 m deep, show that the experiments located in sloping topography accumulated larger amounts of carbon than those established in flat areas. The reasons behind this trend may include a higher erosion of flat soils through greater livestock activity over time, which limited the soil's capacity for aeration and reduced availability of water for better root development.

Objective 2: To make an economic evaluation of the benefits associated with carbon accumulation in these management systems.

Models were developed to financially evaluate land-use changes from poorly managed natural pastures to improved pastures with herbaceous legumes and improved pastures plus forage banks. The methodology followed to achieve this objective is described in detail in Figure 3.2, Section 3.1, Chapter 3. It was used at three scales: global, national, and farm, assessing the outputs and inputs used in the different land use systems for each exploitation.

Two farms types were evaluated. Type I farms were characterized by their smaller size (average of 65 ha) and diverse production obtained through permanent attention from their owners. Carrying capacity ranged from 0.3 to 2.8 animal units (AU) per hectare, with animals receiving additional forages produced by protein and energy banks to supplement grazing on natural pastures. Daily milk production ranged between 1.7 and 4.5 liters per cow.

Type II farms corresponded to the production of dual-purpose commercial livestock. They are characterized by their extension and production volume, with an animal load of 0.9 AU per hectare and an average daily milk production of 5.1 liters per cow. These outputs are regarded as atypical for the region, being the result of genetic selection of animals and the type of health and nutritional management.

When the analysis of carbon capture is widened to include the total system (including soil carbon, aerial biomass, and root biomass), the native forest presents the highest levels of carbon accumulation (182.9 tons of carbon per hectare), of which soil carbon represents 58.5% and that contributed by aerial biomass represents 41.5%. The high level of accumulated carbon in the biomass of roots, trunks, and leaves permit estimating the potential loss of carbon when a native forest is felled to establish pastures, which, under poor management, will become degraded soils 5 years later. *Brachiaria humidicola* pastures under monoculture and in association with herbaceous legumes were found to form the second most important land use for capturing carbon after native forest. Then is natural regeneration, followed by degraded pasture, and, lastly, by *B. decumbens* pastures. The carbon contributed by pasture biomass and which passes to animals for meat and milk production represents between 1.1% and 1.9% of the total carbon content of the total system.

For sloping topography, results show soil as characterized into two major groups: the first group comprises Oxisols that belong to disturbed native forest systems (*B. humidicola* and *B. decumbens* plus legumes) with apparent densities close to 1.0 g/cm^3, which situation does not limit root growth. The pH increases with depth, and nitrogen contents are higher at the surface. This situation allows greater absorption of this element by roots. P values are generally low, regardless of land-use system. The second group belongs to systems that naturally regenerate degraded pastures of *B. decumbens* and *B. humidicola* plus legume. The soils are classified as Ultisols and are characterized by low apparent density in surface layers, increasing to as high as 1.4 g/cm^3 in deeper layers.

Table 6, Section 5.2, Chapter 5, shows statistical comparisons between total and stable carbon accumulation of the two soil groups, the land-use systems belonging to the first group accumulating more total and stable carbon than the group 2 systems at all depths. Generally, stable carbon is greater at depths of 40–100 cm, with an average of 31 tons per hectare, compared with the reported average of 28 t/ha at 0–40 cm. This may be particularly so because roots, which are responsible for fixing carbon to the soil, cannot penetrate deeper than 40 cm. Also, the factors responsible for decomposing organic matter are limited at this depth, for lack of oxygen.

Unlike what was found for flat topography, on the slopes, the factors affecting carbon accumulation in the soil depended, 74% of times, on the land-use system evaluated and only 12% corresponded to unexplained variation (see Table 7, Section 5.2, Chapter 5).

The largest carbon stocks in the system for sloping topography corresponded with those for the other topography: under native forest systems, the C value was 309.5 t/ha; improved *B. decumbens* pastures plus legumes, 175.9 t/ha; *B. humidicola* under monoculture, 165.5 t/ha; and, lastly, natural regeneration, 133.2 t/ha (see Table 8, Section 5.2, Chapter 5).

Comparing total carbon in new experiments *(Brachiaria* Mulato II, *B.* Mulato II in association with *Arachis* pintoi, protein banks, and natural regeneration)

FIRST PART:
RESULTS OBTAINED VERSUS PROPOSED OBJECTIVES

Objective 1: To compare several land-use systems to identify those economically more attractive to farmers while having high levels of carbon accumulation.

Comparing long-established systems for total carbon

To understand the capacity for carbon capture of long-established systems, seven (7) land uses were compared. Each had more than 10 years of establishment on flat or sloping topography under an extensive dual-purpose livestock system (see Table 3, Land Use Systems – Tropical Humid Forest, Amazon Region, Colombia, in Chapter 2 on Methodology for Biophysical Research). Chapter 2 also provides details of farm characterization.

Eight variables were measured in the soil: apparent density (g/cm^3), pH, texture (% sand, % clay, and % lime), P (Bray II, mg/kg), CEC (cmol/kg), total carbon (g/kg), oxidisable carbon (g/kg), and total nitrogen (mg/kg). Figure 1, Chapter 2, shows the design of the scheme followed to conduct soil sampling in different land-use systems. Aerial biomass from different treatments was also evaluated, with the biomass of grasses being measured with the BOTANAL technique (Figure 2, Chapter 2) and the arboreal biomass measured.

The results of the characterization showed that the soils of the Amazon Region are poor, acid, and highly uniform, as corroborated by the low coefficients of variation found for the two topographies evaluated. Moreover, evidence exists for some elements, essential for the growth of most crops such as P and N, as being limiting, together with high levels of pH (see Section 5.2, Chapter 5, on *Soil C stocks and C in biomass in long-established systems: statistical analysis and interpretation*).

With reference to carbon accumulations over time in flat topography (Table 2, Section 5.2, Chapter 5), to summarize, improved pastures managed under monoculture and in association with herbaceous legumes accumulated levels of carbon in the soil as high as those of native forest, with or without anthropogenic intervention. Moreover, 43% of total variation in the accumulation of total carbon in the soil to a depth of 1 meter equivalent is represented by the land-use system (Table 3, Section 5.2, Chapter 5). Spatial variation represented only 10% of variation and the remaining 47% is unexplained. For stable carbon, representativeness is similar to that for total carbon, with 51% of variation being explained by land use, 8% by spatial variability, and the remaining 41% unexplained. These results suggest that, in flat topography, land use is a determining factor for carbon accumulation.

Final Report on Research Activities in the Amazonian Ecosystem

Bertha Leonor Ramírez Pava

Period of project implementation: 1 December 2001–30 November 2006

Institutions: Universidad de la Amazonia, CIPAV, CIAT, CATIE, and Wageningen University

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Lina Mejía	Undergraduate student, co-researcher
Gerardo Silva	Farmer, "La Guajira" Farm
Rodrigo Silva	Farmer, "La Palma" Farm
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In this report, we summarize the achievements obtained during the execution of a research project to evaluate the capacity for carbon capture of pasture, agropastoral, and silvopastoral systems of the tropical rainforest ecosystem in the Amazon Region. The presentation has two parts: the first discusses the results obtained with each proposed objective, and the second discusses the contributions the project made to the institutional building of the University of Amazonia.

The results in detail are presented and analyzed in the scientific book entitled ***Carbon Sequestration in Tropical Grassland Ecosystems***, an edited version of which will be presented as part of this report. For this reason, we make frequent reference to each chapter and, particularly Chapter 5, *Results Humid Tropical Forest Ecosystem, Amazon Region, Colombia*.

Final Report: Humid Tropical Forest, Amazonia, Colombia

Annex 1

Final Report by Ecosystem

implementation activities, revise project progress and receive suggestions from invited guests, particularly from decision-makers from the environmental public policy sector.

Recommendations from the various meetings were recorded in the project Technical Reports and applied accordingly.

The various meetings were held as follows:

- First International Coordination Meeting at CIAT, December 19-22 2001.
- Second International Coordination Meeting at CATIE, June 2002
- Third International Coordination Meeting at CIAT, June 2003
- Fourth International Coordination Meeting at CATIE, July, 2004
- Fifth International Coordination Meeting at CIAT, Aug 16-19, 2005
- Sixth International Coordination Meeting at Punta Leona, Costa Rica, June 2006
- Last Int Coordination Meeting at Santa Marta, Colombia, Oct 12-13, 2006

5. Divulgation of Project Results

- Project objectives, methodology and results were divulgated to farmers, educators, students and researchers, during field days, workshops and local meetings.
- Periodic project results were reported in our **Technical Six-months Reports nos. 1-10**, handled to The Netherlands Cooperation at The Netherlands Embassy in Bogotá, every six months.
- Project results were also published in **national and international papers** and **Congress's Proceedings.**
- Concepts related to Climate Change and Carbon Sequestration in pasture, silvo-pastoral, forage banks and forests, in the project ecosystems, were published in the **"Booklet for Farmers, Educators and Students"** (Spanish)
- A visual description of the project framework, objectives, methodology and results was produced in the **Project Video** (English and Spanish)
- Scientific project results are presented in the **"Scientific Book"** to be published and distributed by Wageninge International Publishers, The Netherlands.

The project video in Spanish and English, the Booklet for Farmers and the Scientific Book form an integral part of the present Final Technical Report.

6. Executed 5-year budget

Budget tables 1-10 included as **Annex 2** of this report show budget execution for the 5 years of project implementation. The tables show project executed funds for the total project and per institution; per activity; per year and for the 5-year period; and discriminated by donor and matching funds.

years. The great surprise was that, despite the Colombian Constitution of 1991 recognizing sustainable development and carrying 50 articles on the environment, *Vision 2019* lacks the environmental theme in both its two governing principles and its four major objectives (environmental sustainability, sustainable development, social development, and economic development). A great opportunity exists for the public and private sectors to help fill this gap. And the present project offers this opportunity.

- Given the Project's nature and objectives, its conclusions, recommendations, and studies of the levels and potential for carbon sequestration of different land uses should also be done holistically, as well as for individual ecosystems.
- That is, the Project should show it delivers solutions that contribute social, economic, and environmental benefits to small farmers in ecosystems that are vulnerable to climate change.
- The project contributes to international policy on Climate Change. It is important to emphasize that project results open the door to new living systems, besides reforestation and aforestation, to enter the international carbon market. These new systems are improved and well-managed pasture, agropastoral, silvopastoral and agroforestry systems to be established on degraded areas in developing countries' ecosystems vulnerable to climate change.

How to ensure that the Project's results support policy decisions?

a. Seek the support of a policy maker who can translate the Project's results for policy decision makers, and who is responsible for drafting one or more policy papers that are different to but highly complements the scientific articles that the Project publishes. The profile of this professional would therefore differ from that of the Project's current members.
b. Look for connection with other projects of international cooperation and so orient its initiatives on environmental management. In this regard, The Netherlands Cooperation has an important role in integrating results generated by different projects. Invited guests suggested that one or more follow-up meetings must be held with the Netherlands Cooperation and the group of decision-makers participant at both meetings.
c. Contribute valuable elements to the *National Action Plan for the Struggle against Desertification and Drought.*
d. Expand its evaluations to two important ecosystems for Colombia: the native savannas of Orinoquía and "Páramos" region.
e. Present results seeking to benefit policy on forest conservation and adequate land management.
f. Analyze information on soils derived from the Project's methodology that would help improve initiatives on better land management by small farmers.
g. Make its conclusions and final recommendations holistically, seeking to favour strategies that aim to help overcome poverty without degrading the environment.

4. Technical & administrative coordination (2001-2006)

Seven International Coordination Meetings were held during the 5-year project period. The purpose of these meetings was to agree on methodological aspects, project

2. The Project's scientific data are useful for improving the precision of national estimates of the balance of emissions, particularly CO_2.
3. Its results serve to define lines of action for the Government on the issue of its *Policy on Climate Change*, specifically actions for mitigation and adaptation.
4. Its scientific methodology can be extrapolated to other environments, for example, research on other land ecosystems or other production systems, and could be even useful for research on aquatic ecosystems such as mangroves.
5. The Project must expand its research to other ecosystems, particularly native savannas and "Páramo" regions.
6. It must also expand its research to other land use systems such as forest plantations.
7. The methodology generated by the Project to evaluate, estimate, analyze, and interpret carbon sequestration is important for supporting the *Primer of Good Practices* described in the MAVDT's *Second Communication on Climate Change*.
8. This Project's results go beyond the issues of carbon sequestration and climate change. They also contribute solid scientific data and documented recommendations on many other issues such as soil improvement practices; improved practices of livestock production that are environmentally sustainable in ecosystems vulnerable to climate change; employment generation; social and economic benefits of improved and well-managed pastoral, agropastoral, and silvopastoral systems; and the potential of silvopastoral and pastoral systems to contribute environmental and economic services to the farmer in four contrasting ecosystems.
9. This Project opens the door to other living systems, besides aforestation and reforestation that can mitigate the adverse effects of climate change. It opens the door to improved and well-managed pasture, silvopastoral, and agroforestry systems. It accordingly contributes elements of policy on this issue of world importance.

Project contribution to decision-making in public environmental policy was expressed as follows:

- For Colombia, this type of research is highly significant for encouraging negotiations on the issue of climate change as it is very important that international negotiation is sustained in systematic scientific research. Analyses of the Project's results can be used in Colombia's negotiations on this issue.
- This Project goes well beyond the issue of climate change. It contributes solid scientific information on many other aspects such as scientific methodology; sustainability through environmentally friendly pastoral and silvopastoral systems that are economically attractive to the farmer. It contributes to National Policy on Desertification and National Policy on Biodiversity. It has a capacity for extrapolating research results.
- "What is the relationship between scientific research and public policy?" Scientific research and public policy form a significant relationship. In the last 15 years, environmental research in Colombia has increased and, although much is yet to be done, it is good to ask now how national science has affected policy. For example, the current government has just issued the document *Vision 2019: A Proposal for Discussion*, which projects the country's future for the next 14

Invited guests at the 2005 meeting were:

- Dr Claudia Rincón, Director of Planning, Colombian Ministry of the Environment (MAVDT), Bogotá
- Dr Leonardo Muñoz, Director of Ecosystems, MAVDT, Bogotá
- Dr Carlos Costa, Director, IDEAM (National Institute of Hydrology, Meteorology and Environment), Bogotá
- Captain Dr Francisco Arias, Director, INVEMAR (National Marine Research Institute), Santa Marta
- Dr Camilo Aldana, Director, CONIF (National Forestry Research Institute), Bogotá
- Dr Manuel Rodríguez, Colombian ex-Ministry of the Environment and International Consultant on Environmental Policy Issues

Invited guests at the 2006 meeting were:

- Dr Katherina Bach, Director of Climate Change, Colombian Ministry of the Environment (MAVDT), Bogotá
- Dr Carlos Costa, Director, IDEAM, Bogotá
- Dr. Fernando Gast, Director, von Humboldt Institute, Bogotá
- Dr Manuel Rodríguez, Colombian ex-Ministry of the Environment and International Consultant on Environmental Policy Issues
- Dr Juan Mayr, Colombian ex-Ministry of the Environment and International Consultant on Environmental Policy Issues
- Dr Emiro Bohórquez, Director of Environmental Planning, CORPOGUAJIRA, (Regional Environmental Corporation for Guajira Department), Riohacha
- Dr Carlos Gómez, researcher, IDEAM, Bogotá
- Dr Fernando Casas, Environmental Economist, von Humboldt Institute, Bogotá
- Dr Douglas White, Environmental Economist, CIAT (International Centre for Tropical Agriculture), Cali

The discussion and recommendations arisen from both groups of decision-makers answered the following questions: **"Where does this Project leave us?"** and **"To which policy issues does this project contribute?"**. Summary comments follow.

The project was considered to represents an unusual partnership between highly heterogeneous research centers, some highly qualified, some of lesser trajectory. An alliance between national centers of regional character, with international centers. An alliance between the scientific communities of developed and developing countries. And yet it produced very important results. The Project's Direction should be congratulated on its excellent leadership.

Project results contribute to the following environmental policy issues:

1. The Project contributes documented and tested methodology for evaluating carbon sequestration in pastoral, silvopastoral, and forest systems in contrasting and heterogeneous tropical ecosystems.

Tropical Forest, Amazonia in Colombia, extending into similar environments in the neighbouring Amazonian countries (Peru, Brazil, Bolivia and Ecuador).

The next table indicates the extent (in km^2) and location (countries) of the extrapolation region of each one of the Project's research sites. (ISRIC Report, 2006)

Ecosystem	Research site	Extrapolation area (km^2)	Extrapolation region (countries and extension in km^2)
1. Andean Hillsides, Colombia	Dagua	7000	Colombia (6000) Ecuador (1000)
	Dovio	3000	Colombia (2000) Ecuador (60) Peru (400)
2. Humid Tropical Forest, Amazonia, Colombia	Flat topography	288000	Brazil (111000) Colombia (112000 Peru (60000) Ecuador (4000) Venezuela (1000)
	Mild-slope topography	80000	Colombia (60000) Brazil (19000) Guyana (1000)
3. Humid Tropical Forest, Costa Rica	Pocora	750	Costa Rica (700) Guatemala (25) Panama (25)
4. Sub-humid Tropical Forest. Costa Rica	Esparza	1300	Costa Rica (150) Nicaragua (50) Panama (1100)

ISRIC Extrapolation Study is annexed to the present Final Technical Report.

Objective 6

Provide policy recommendations at local, national and international level

Achievments: Policy Recommendations

The following paragraphs summarize the opinions and contributions offered by a distinguished group of decision-makers invited by the project direction to identify how project results could help the decision-making process in public environmental policy. Two important meetings with decision-makers from the Colombian Government were held. The first, conducted at CIAT, Cali, Colombia, on August 15-19, 2005. The second, conducted at Irotama Hotel, Santa Marta, Colombia, on October 13, 2006.

Achievment: Extrapolation Study done with ISRIC, The Netherlands

The Project signed a contract on April 28, 2005 with the International Soil Reference and Information Centre (ISRIC) to produce: (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 Project's research results in each ecosystem; (2) a database accompanying the maps; (3) a report explaining the methods and results.
Presentation of results of this study, together with ISRIC Report, was made by Dr. Vincent van Engelen from ISRIC, Wageningen, The Netherlands, on June 28, 2006, during the Project's VII International Coordination Meeting held at Punta Leona, Costa Rica on June 28 – July 1, 2006. The study produced digital and physical maps showing the extrapolation region of project's results from each research site to Tropical America. Extrapolation criteria were three: a) climate (represented by "length of growing period"; b) topography (expressed by altitude and slope); and soil type (according to FAO).

Soil type names of Project's research sites were given to ISRIC according to USDA Soil Taxonomy classes (1999). However for the present extrapolation study, ISRIC used soil taxonomy names according to FAO classification. Therefore, original soil types names were reclassified according to the "Revised Legend of the Soil Map of the World" (FAO et al., 1988), with no discrepancy, as follows:

Ecosystem	**Research site**	**Soil type name (USDA, 1999)**	**Soil type name (FAO, 1988)**
1. Andean Hillsides, Colombia	Dagua	Inceptisols, Typic Dystropepts	Umbric Andosols
	Dovio	Inceptisols/ Andisols, Typic Dystropepts	Dystric Cambisols
2. Humid Tropical Forest, Amazonia, Colombia	Flat topography	Ultisols, Typic Kandiudults and Typic Paleudults. Also Ultisols, Oxic Dystropepts	Haplic Acrisols
	Mild-slope topography	Ultisols, Typic Paleudults and Typic Hapludults	Haplic Ferrasols
3. Humid Tropical Forest, Costa Rica	Pocora	Inceptisols	Dystric Cambisols
4. Sub-humid Tropical Forest. Costa Rica	Esparza	Inceptisols and Entisols	Cambisols

The extrapolation regions of project results include: (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; and (c) Humid

A profit-maximizing farmer would switch to a land management systems with capacity to sequester C, if the net present value for the C sequestering livestock systems alternative (NPV_A) is higher than the one for the current land management system (NPV_C), such that $NPV_A > NPV_C$. In other words, the incremental NPV for the investment must be positive ($NPV_A - NPV_C > 0$). The incremental NPV for each of the possible investments options was determined by computing the cash flow for each year of the investment's economic life.

Objective 4

Develop scientifically solid methodologies for the evaluation and estimation of C-stocks and C-sequestration rates in these tropical systems and ecosystems.

Achievments

The project team developed methodologies for:

- Field evaluation of soil and vegetation C-stocks
- Evaluation of C in the tree aerial biomass, using allometric equations
- Mathematical estimation of soil carbon stocks, using estimates based on fixed soil mass per soil pit.
- Statistical analysis of resulting bio-physical and socio-economic databases, and the interpretation of results.
- Extrapolation of project results using geo-referenced databases on soil type, topography and climate, and the representation of the extrapolation region in digital maps.

Objective 5

Extrapolate project results to similar environments in Tropical America.

An important project objective, was the extrapolation of project results on carbon sequestration 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 was 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.

Stages for the socio-economic research.-
To achieve the objectives for the socio-economic component listed above, the information was analyzed in three stages. **Stage 1** corresponded to the socio-economic description of the farms participating in the project, and to the characterization of conventional livestock production systems vis-à-vis C-sequestering livestock systems regarding production levels, production costs and management conditions. This stage was mainly descriptive and static, and was based on information coming form the farm surveys conducted . **Stage 2** consisted of modeling the financial feasibility of investing in C sequestering livestock systems. Once conventional livestock production systems and C sequestering livestock systems were characterized and their production costs and sales were estimated, models were developed to explore the financial feasibility of investing in C sequestering livestock systems under different scenarios considering the presence or absence of payments for C sequestration. This stage involved dynamic modeling and integrating results from the socio-economic research with results from the bio-physical research on the capabilities of different land management systems to sequester C. Finally, **Stage 3** translated the results of the bio-physical and socio-economic research into policy initiatives and recommendations to promote the implementation of land management systems with capacity to sequester C. This phase was based on the results generated by the models on the financial feasibility of C sequestering livestock systems, and from their interpretation in the context provided by the application of the conceptual framework described above.

Data gathering .-
Data needed for the socio-economic analysis were obtained from: (i) a farm survey, (ii) registers of farm production and activities and (ii) secondary sources.

Data Analysis.-
Farm production and financial indicators were estimated for each farm at each ecosystem studied. Using these data, simulation of investment scenarios was carried-out using a benefit-cost analysis to evaluate the financial viability of investing in improved systems. Accordingly, models were developed taking poorly-managed natural pasture as the starting point for the comparison. Table10 shows models developed.

Table 10. Financial models developed within each sub-ecosystem.

	Direction of the investment	
Site	From (current practice)	To (C sequestering livestock systems)
Andean hillsides, Colombia	Natural pasture, poorly managed	Association of introduced pasture + leguminous + dispersed shade trees
	Natural pasture, poorly managed	Introduced pasture + leguminous + dispersed shade trees + fodder bank
Semi-humid forest, Costa Rica	Natural pasture, poorly managed	Introduced pasture + dispersed shade trees
	Natural pastures + concentrates	Natural pastures + fodder bank
Amazon Region, Colombia	Natural pasture, poorly managed	Association of introduced pasture + dispersed shade trees
	Natural pasture, poorly managed	Association of introduced pasture + leguminous + dispersed shade trees + fodder bank

This report describes the various project activities: in Chapter 2 the materials and methods are described; Chapter 3 discusses the results, and Chapter 4 gives conclusions and options for future improvements.

2. MATERIALS AND METHODS

2.1 Characterization of the ecosystems

Agro-ecological conditions of the research sites were defined in broad terms by CSEQ: 'Tropical Andean Hillsides', or '(Sub)humid Tropical Forest'. To allow a geographical extrapolation to similar environments the four ecosystems were characterized in terms of their broad agro-ecological conditions using the Global Agro-Ecological Zones project - GAEZ (FAO-IIASA 2000). The GAEZ map shows 15 Length of Growing Period (LGP) classes of 30 days intervals (see Appendix 1; Figure 2). LGP was calculated by GAEZ with the following assumptions and definitions:

- water balance for a standard FAO reference crop;
- soil with 100 mm of Available Water Content (AWC);
- average climatology data from the Climatic Research Unit of the University of East Anglia (CRU) for the years 1961-90 (0.5 degrees) interpolated to 5 arcminutes.

The ecosystems of the research sites were further characterized by elevation and slope, both available from GPS data collected by CSEQ at the sites of ecosystems 1 and 2. Missing elevation data and slope gradient of ecosystems 3 and 4 were derived from the global SRTM 90m Digital Elevation Model - DEM (USGS 2003). Slight discrepancies were observed between elevation data derived from the SRTM and the GPS readings.

Soil characterizations of the research sites are based on the work of CSEQ (Carbon Sequestration Project 2005a, b). Classification is according to the US Soil Taxonomy (Soil Survey Staff 1998). Selected analytical data are available for some of the profiles (soils of the Andean Hillsides and the Amazonia ecosystem), focusing on organic matter related data. Morphological description data, however, are lacking. Descriptions and analytical data from the Costa Rica sites were not available. As the spatial soil information - SOTERLAC - follows versus the Revised Legend of the Soil Map of the World (FAO *et al.* 1988), the soil names had to be reclassified to the Revised Legend. The lack of standard profile descriptions and the limited analytical data only permitted a rough reclassification - more detailed profile characteristics would be needed for more detailed assessments.

Spatial soil data were derived from the Soil and Terrain Database of Latin America and the Caribbean at scale 1:5 M (Dijkshoorn *et al.* 2005). Mapping units contain information on the terrain units and their soil components. Each mapping unit (SOTER unit) consists of up to three soil components of which the proportional percentage (relative area) is given.

Table 1 gives the ranges of ecosystem attributes.

Table 1. Selected ecological conditions of the four CSEQ ecosystems.

Ecosystem	**Site**	**Soils**	**LGP**	**Altitude (m)**	**Slope (%)**
1) Tropical Andean Hillsides, Colombia	Dagua	Typic Dystropepts	2	1300-1400	15-45
	Dovio	Typic Dystrandepts	2	1700-2000	35-65
2) Humid Tropical Forest, Amazonia, Colombia	La Guajira	Typic Kandiudults, Paleudults	1	200-300	2-5
	Pequín	Typic Paleudults	1	200-300	10-15
	Santo Domingo	Oxic Dystropepts	1	200-300	2-5
	Balcanes	Typic Paleudults, Hapludults	1	200-300	10-15
3) Humid tropical forest, Atlantic Coast, Costa Rica	Pocora	Inceptisols	1	200-300	0-5
4) Sub-humid tropical forest, Pacific Coast, Costa Rica	Esparza	Inceptisols/ Entisols	4	200-300	15-30

Sources: (Carbon Sequestration Project 2003, 2005a, b; FAO-IIASA 2000; USGS 2003)

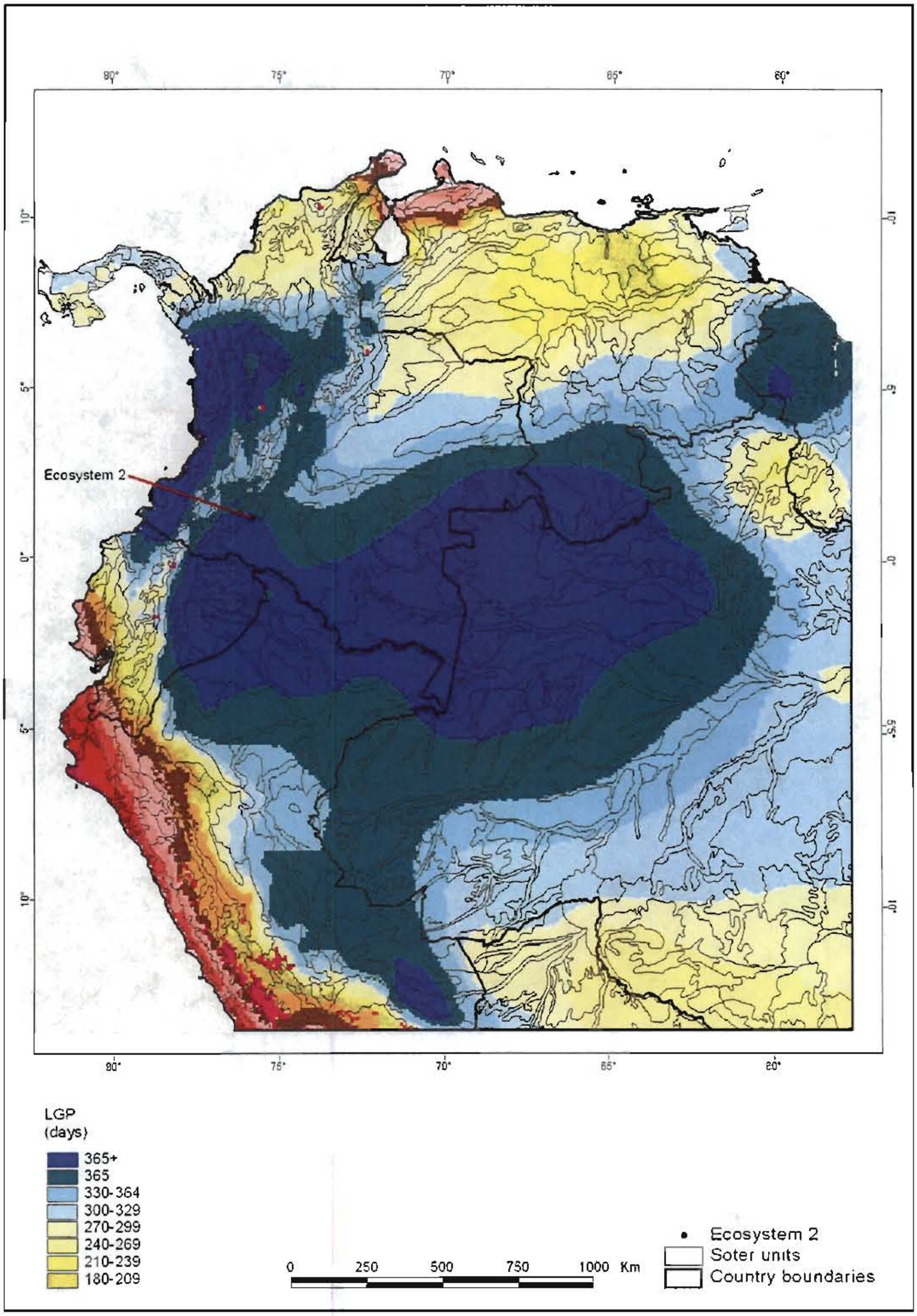

Figure 2. Length of Growing Period (LGP). (FAO-IIASA 2000)

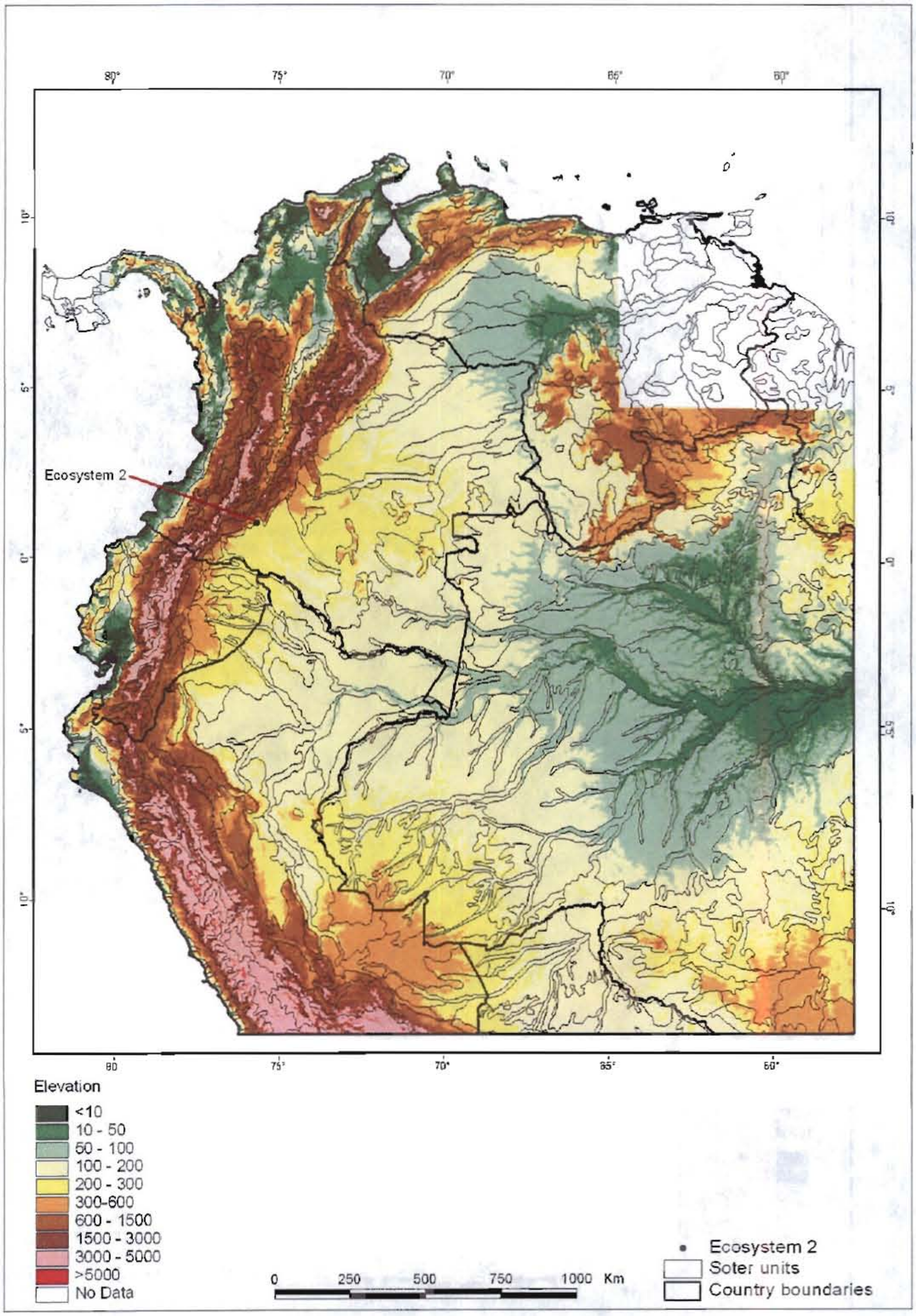

Figure 3. Elevation in m from SRTM 90 DEM. (USGS 2003)

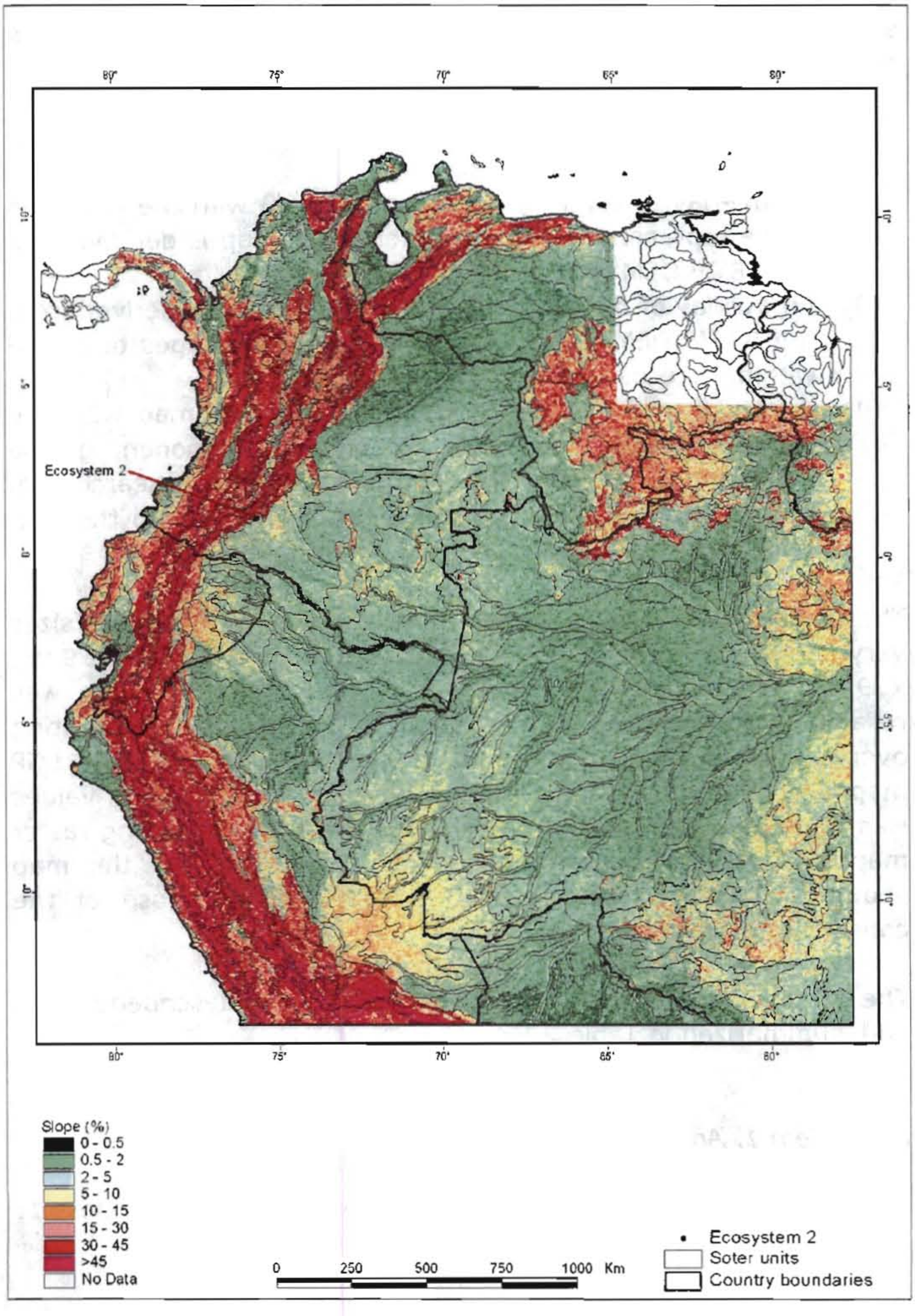

Figure 4. Slope classes derived from SRTM 90 DEM.

2.2 Extrapolation method

Selection of areas with similar characteristics for each of the four ecosystems consisted of:

(1) A selection of the LGP class corresponding to the CSEQ ecosystem site (Figure 2);
(2) An overlay of the map resulting from (1) with the elevation range representing the ecosystem: this map is derived from the SRTM DEM (Figure 3);
(3) An overlay of map (2) with the slope class map derived from the SRTM DEM (Figure 4) using the slope ranges observed within the ecosystem;
(4) An overlay of map (3) and the SOTER unit map with the condition: soil classification of the soil component of the SOTER unit = soil classification in the selected research site. Figures 5 and 6 show areas having soils similar to those of ecosystem 2.

The maps used in steps 1, 2 and 3 are in raster format. Cells sizes vary between 90 m for the SRTM DEM to 5 arcminutes (about 9 km x 9 km at the equator) for the LGP map. The LGP map was resampled to the pixel size of the SRTM to make the resulting overlay less blocky, while maintaining the resolution of the LGP map. Selection of the appropriate LGP, slope and elevation values was done by a GIS query for each ecosystem. The resulting raster map was vectorized and subsequently combined with the map showing SOTER units that have soils similar to those of the considered ecosystem.

The extrapolation criteria for each ecosystem are described below, and summarized in Table 2.

Ecosystem 1, Andean Hillsides, Colombia

The two sites - Dagua and Dovio - both fall within the LGP class 1: 365 days.

GPS-measured altitudes range between 1439 and 1899 m for the Dagua sites and between 1791 and 1859 m for the Dovio sites. Elevation indicated by the SRTM DEM falls between 1413 to 2137 m. A range of 1400 – 2000 m was taken for the extrapolation.

Slopes at the sites are described as 'moderate and steep' for Dagua and Dovio respectively (Amézquita personal communication), while the DEM quantifies them as 6-16% for Dagua, with a 30-45% outlier in one site, and 3-30% in Dovio. Slopes greater than 10% were used for the extrapolation.

Soils of Dovio are classified as *Typic Dystropepts* corresponding to *Dystric Cambisols* of the Revised Legend (FAO *et al.* 1988). The soils of the Dagua sites are *Typic Dystrandepts* and were correlated to *Umbric Andosols.* According to SOTERLAC, the research sites fall in a SOTER unit with two soil components: 70% *Umbric Andosols* and 30% *Dystric Cambisols.*

Ecosystem 2, Humid Tropical Forest, Amazonia, Colombia

All sites in this ecosystem fall within LGP zone 1': 365 days with year-round excess moisture conditions. Also LGP zone 1: 365 days was used for the extrapolation.

Altitudes for the four sites in the ecosystem range from 232 to 244 m according to the DEM. Conversely, the altitude of 800 m given by CSEQ (Carbon Sequestration Project 2003) therefore could not be used. Instead, an altitude of less than 300 m was used in the extrapolation.

Slopes of the sites range from 2–5 % as determined by the DEM, while. Amézquita (personal communication) described the slopes as flat to mild. Percentages from 0 to 5 have been used for the extrapolation.

Soils range from *Typic Kandiudults, Paleudults* and *Hapludults* to *Oxic Dystropepts*. Tentatively, they were correlated with *Haplic Acrisols* and *Ferralsols.* According to SOTERLAC, the research site occurs in a unit with 70% *Haplic Acrisols* and 30% *Haplic Ferralsols.*

Ecosystem 3, Humid Tropical Forest, Atlantic Coast, Costa Rica

All sites in this ecosystem fall within LGP zone 1: 365 days. Zone 1 was used for the extrapolation.

Altitudes for the sites in the ecosystem range from 25 to 190 m in the DEM. An altitude of less than 200 m was used in the extrapolation.

Slopes of the sites range from 0-5 % as determined by the DEM. These percentages have been used for the extrapolation.

Soils of the sites are classified by CSEQ as *Inceptisols*. Tentatively, they have been correlated with *Dystric Cambisols.* The spatial information of SOTERLAC indicates for the site a unit with 50% *Dystric Cambisols*, 25% *Eutric Gleysols* and 25% *Dystric Fluvisols*. of which only the first soil type has been used in the extrapolation.

Ecosystem 4, Sub-humid Tropical Forest, Pacific Coast, Costa Rica

All sites in this ecosystem fall within LGP zone 4: 270 -299 days. This zone was used for the extrapolation.

Altitudes for the sites in the ecosystem range from 25 to 300 m in the DEM. An altitude of less than 300 m was used in the extrapolation.

Slopes of the sites range from 15-30% as determined by the DEM. These percentages have been used for the extrapolation.

Soils of the sites are classified as *Inceptisols* and *Entisols* by CSEQ corresponding with Cambisols of the Revised Legend. The SOTER unit that covers the research area comprises *Cambisols*: *Umbric* (50%), *Dystric* (25%) and *Eutric* (25%).

Table 2. Criteria for extrapolation of research sites characteristics.

Ecosystem	**Site**	**Soil name a)**	**% b)**	**LGP c)**	**Altitude (m)**	**Slope (%)**
1) Tropical Andean Hillsides, Colombia	Dagua	Umbric Andosols	75	1	1200-2000	>10
	Dovio	Dystric Cambisols	25	1	1200-2000	>10
2) Humid Tropical Forest, Amazonia, Colombia	all	Haplic Acrisols/ Ferralsols	70 30	1' and 1	< 300	0-5
3) Humid tropical forest, Atlantic Coast, Costa Rica	Pocora	Dystric Cambisols	50	1	< 300	0-5
4) Sub-humid tropical forest, Pacific Coast, Costa Rica	Esparza	Cambisols: Umbric Dystric Eutric	 50 25 25	4	< 300	15-30

a) Soil classification from the SOTERLAC database (Dijkshoorn *et al.* 2005)

b) Relative area of the soil with the SOTER unit.

c) LGP 1'= 365+ days, LGP 1 = 365 days, LGP 4 = 270-299 days

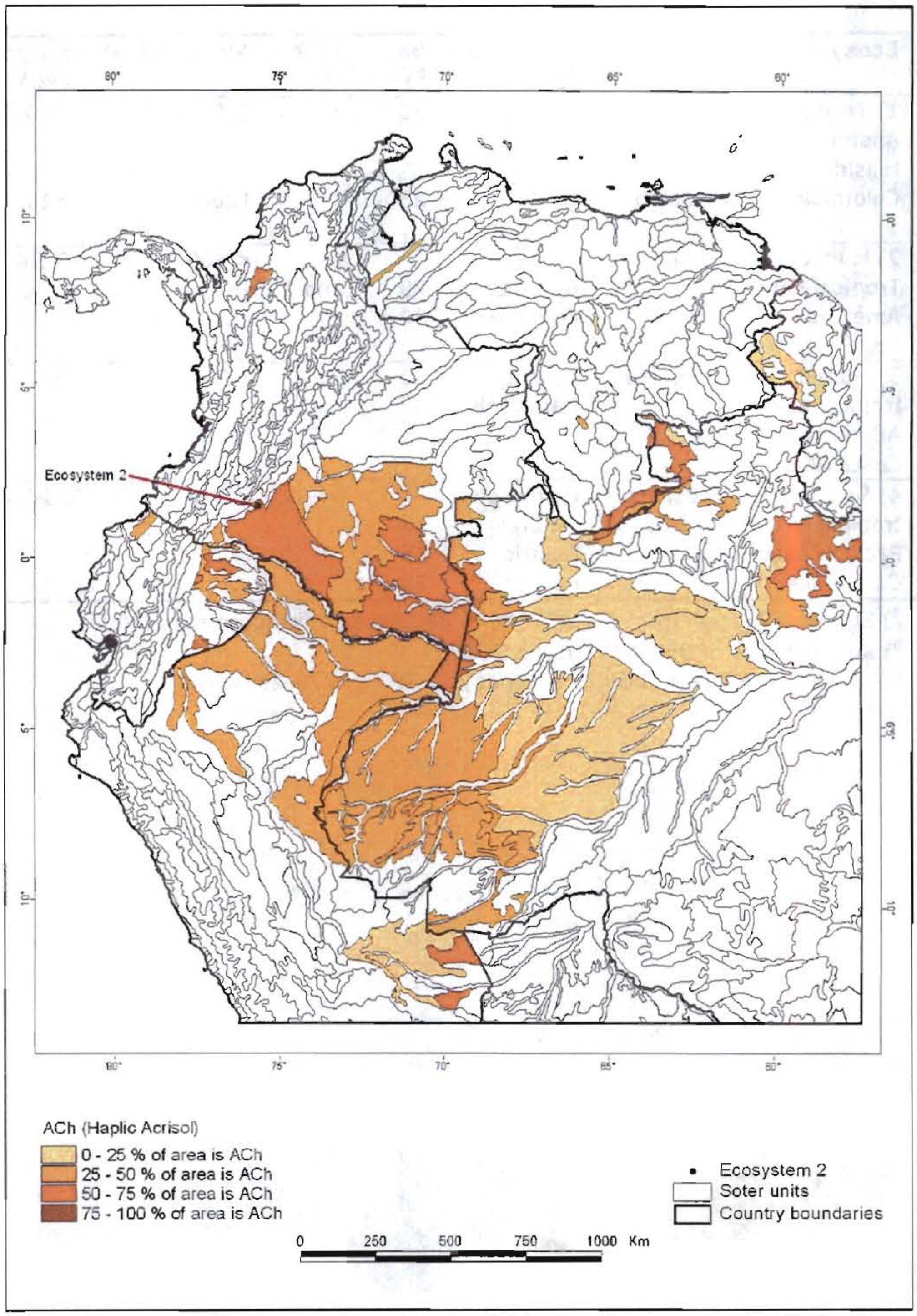

Figure 5. Extent and proportion of *Haplic Acrisols.* (Dijkshoorn *et al.* 2005)

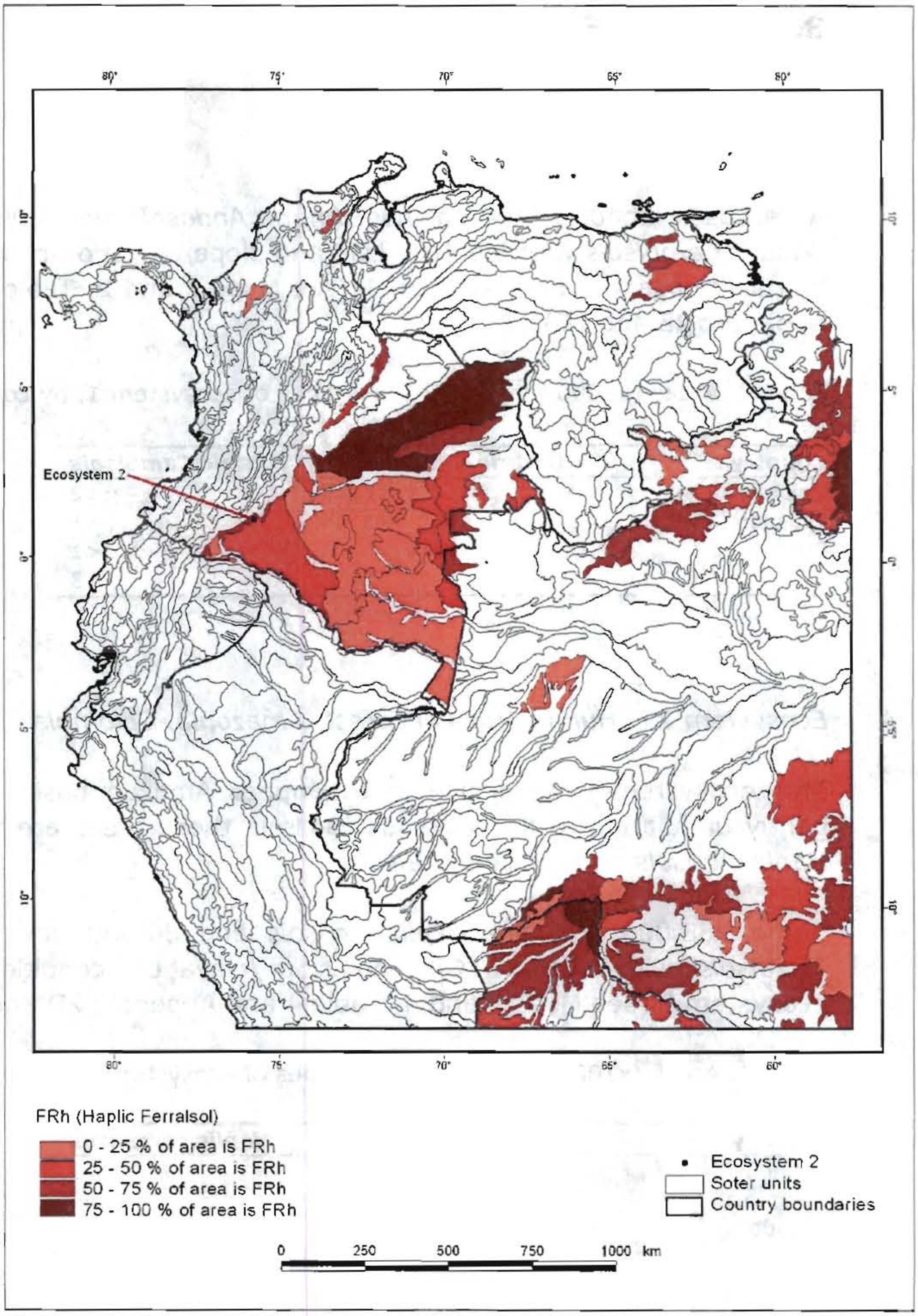

Figure 6. Extent and proportion of *Haplic Ferralsols*. (Dijkshoorn *et al.* 2005)

3. RESULTS

Ecosystem 1 - Andean Hillsides, Colombia

An areas of about 7,000 km^2 has *Umbric Andosols* and 3,000 km^2 *Dystric Cambisols* with identical LGP and slope/elevation conditions as those observed in ecosystem 1 (see Maps 1 and 2, Table 3 and Appendix 2B and 2C).

Table 3. Areas (x1000 km^2) for the soil types of ecosystem 1, by country.

Country	***Umbric Andosols***	***Dystric Cambisols***
Colombia	6	2
Ecuador	<1	<1
Peru	-	<1
Total	7	3

Ecosystem 2 - Humid Tropical Forest, Amazonia, Colombia

This ecosystem is extensive in the upper Amazon basin in the gently undulating to flat lowlands. Soils in these areas are mainly *Haplic Acrisols* and *Haplic Ferralsols.*

Some 288,000 km^2 are *Haplic Acrisols* and 80,000 km^2 *Haplic Ferralsols* with similar LGP and slope/elevation conditions as ecosystem 2 (see Maps 3 and 4, Table 4 and Appendix 2D and 2E).

Table 4. Areas (x1000 km^2) for the soil types of ecosystem 2, by country.

Country	***Haplic Acrisols***	***Haplic Ferralsols***
Brazil	111	19
Colombia	112	60
Ecuador	4	-
Guyana	-	1
Peru	60	-
Venezuela	<1	-
Total	288	80

Ecosystem 3 - Humid Tropical Forest, Atlantic Coast, Costa Rica

An area of less than 750 km^2 has *Dystric Cambisols* with identical LGP and slope/elevation conditions as ecosystem 3 (see Map 5, Table 5 and Appendix 2F).

Table 5. Areas (x1000 km^2) under Humid Tropical Forest (ecosystem 3), by country.

Country	***Ecosystem 3***
Costa Rica	0.7
Guatemala	<0.1
Panama	<0.1
Total	0.7

Ecosystem 4 - Sub-humid Tropical Forest, Pacific Coast, Costa Rica

An area of about 1,300 km^2 has *umbric, dystric* or *eutric Cambisols* with identical LGP and slope/elevation conditions as ecosystem 4 (see Map 6 and Table 6 and Appendix 2G, 2H and 2I).

Table 6. Areas (x1000 km^2) of the soil types of ecosystem 4, by country.

Country	***Umbric Cambisols***	***Dystric Cambisols***	***Eutric Cambisols***
Costa Rica	<0.1	<0.1	<0.1
Nicaragua	-	<0.1	-
Panama	<0.1	0.7	0.4
Total	<0.1	0.8	0.4

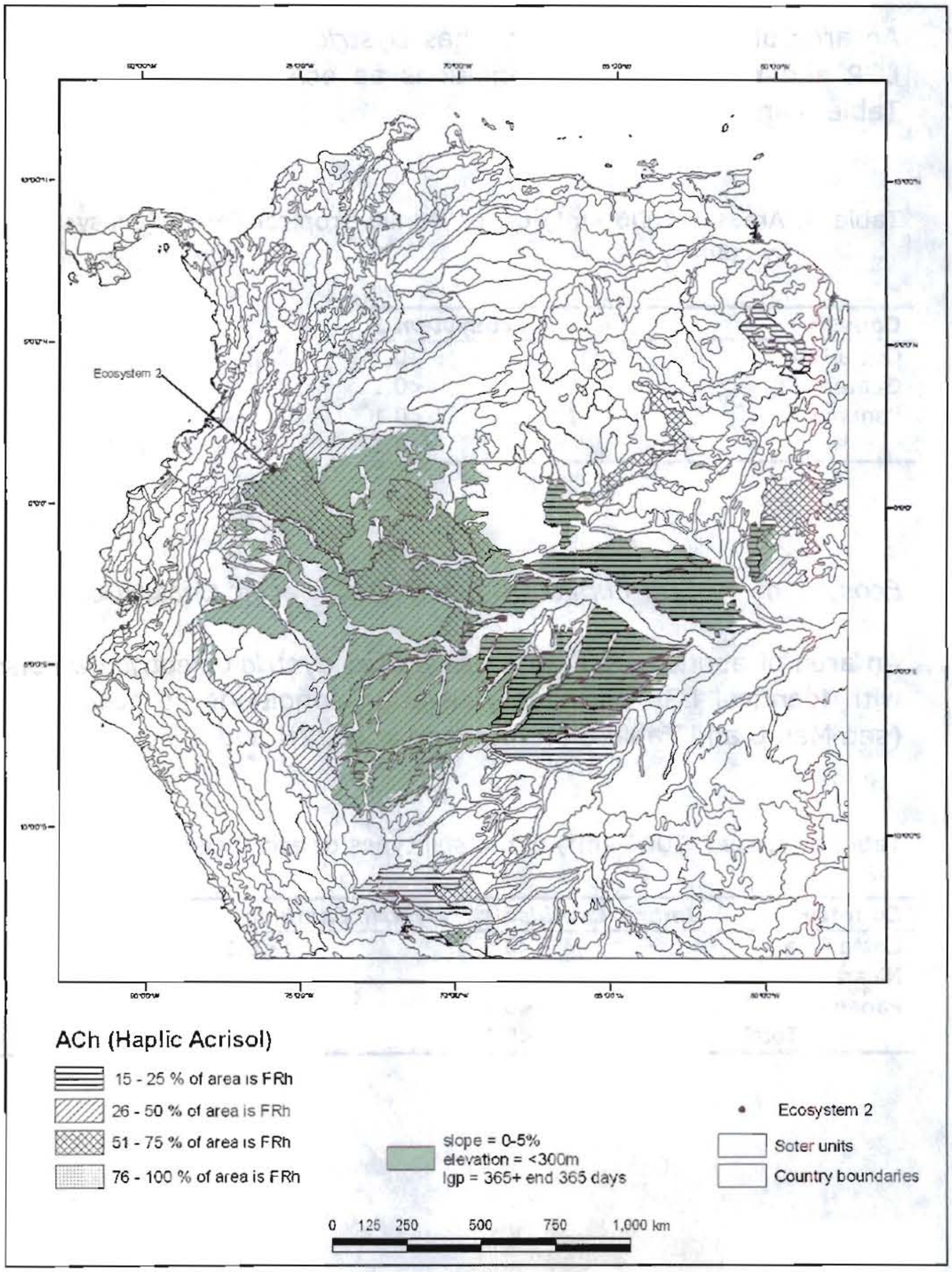

Figure 7. Areas of *Haplic Acrisols* having similar LGP, elevation and slope conditions as Ecosystem 2.

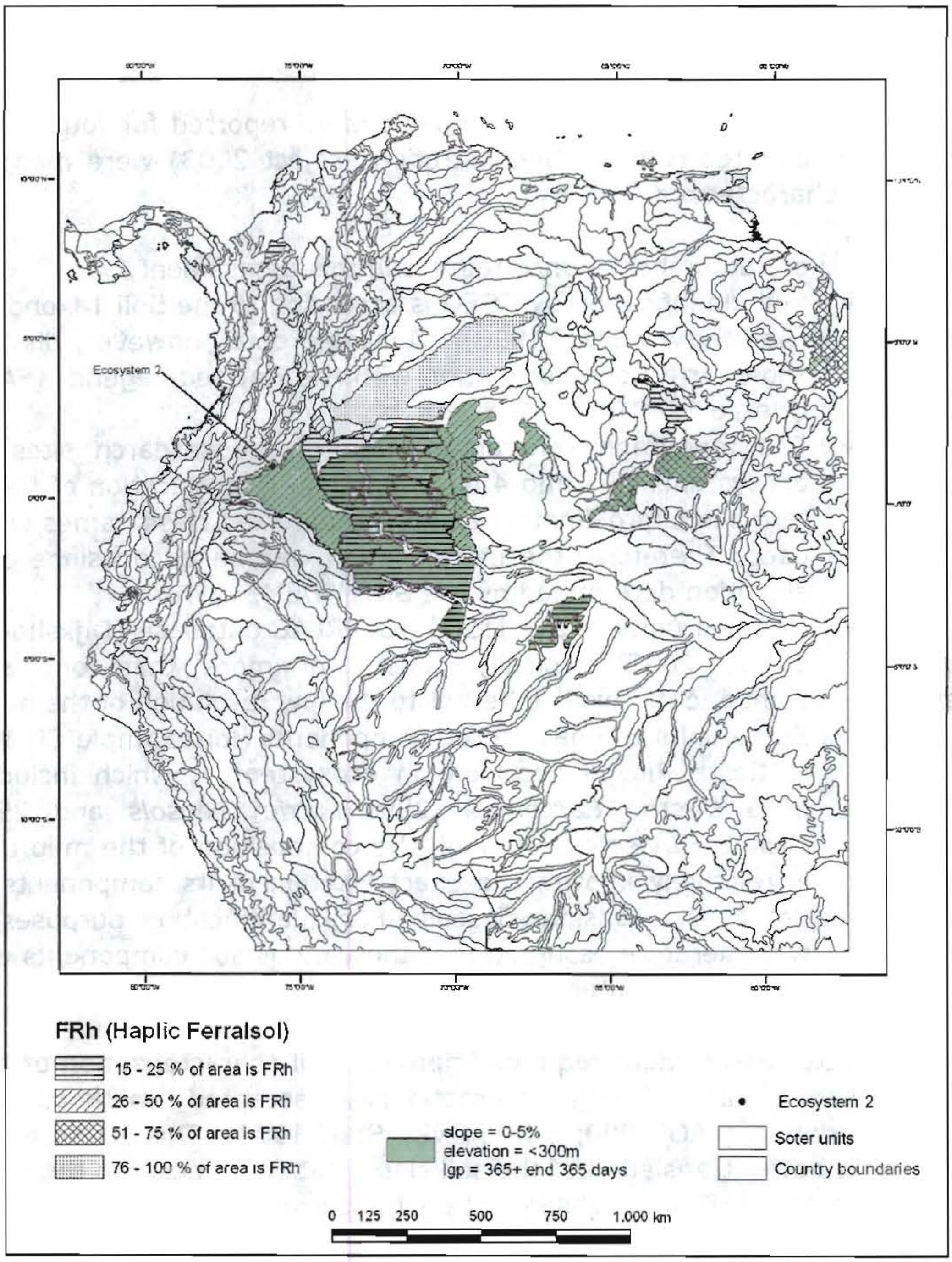

Figure 8. Areas of *Haplic Ferralsols* having similar LGP, elevation and slope conditions as Ecosystem 2.

4. CONCLUSIONS

Areas with similar ecological conditions as reported for four CSEQ research sites (Carbon Sequestration Project 2003) were mapped and characterized.

There are a number of uncertainties in this assessment:

- Soil identification by CSEQ is according to the Soil Taxonomy (Soil Survey Staff 1998). Available data however, dis not allow for a good correlation with the Revised Legend (FAO-Unesco 1988).
- The topography characterization of the research sites of ecosystems 2, 3 and 4 is descriptive. Quantification of these terms is approximative as no standardized class names were used. Therefore, the extrapolation was based on slope and elevation determined by the SRTM-DEM.
- Mapping units of the 1:5 M SOTERLAC database (Dijkshoorn *et al.* 2005) typically consist of more than one soil component. This is inherent to the low resolution of the map. Some units can have three components (for example CR 183 in Costa Rica - occurring in ecosystem 4, which includes 50% *Dystric Cambisols*, 25% *Eutric Gleysols* and 25% *Dystric Fluvisols*). Although the composition of the map unit is relatively known, the exact location of its components is not at the considered scale. For quantification purposes it was therefore assumed that the various soil components are evenly distributed within a unit.

A better assessment requires improved soil characterization of the research sites, using internationally accepted methods for description (FAO 1990; Soil Survey Staff 1983). This would allow for a better translation of the soil classification names into the ones used in SOTER, and subsequent spatial extrapolation.

Assessment at national scale should be based on more detailed spatial data. The latter are available for Costa Rica, Colombia and Peru, albeit not in SOTER format

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APPENDICES

Appendix 1: Length of Growing Period classes

Length of Growing Period (LGP) classes in days (FAO-IIASA 2000).

LGP class	No. of days	Remarks
1'	365+	year-round excess moisture conditions
1	365	
2	330-364	
3	300-329	
4	270-299	
5	240-269	
6	210-239	
7	180-209	
8	150-179	
9	120-149	
10	90-119	
11	60-89	
12	30-59	
13	1-29	
14	0	year-round moisture deficit

Appendix 2: Extent of areas similar to the four ecosystems

Areas that fit the extrapolation criteria are described in this appendix. Data are listed by SOTER polygon that meets the extrapolation criteria of the ecosystem and, if applicable, per soil type within the ecosystem.

A - Codes used in area data tables.

Column	**Code**		**Description**
1	SUID		SOTER unit ID (country code with number)
		BR	Brazil
		CO	Colombia
		CR	Costa Rica
		EC	Ecuador
		SV	El Salvador
		GT	Guatemala
		GY	Guyana
		HN	Honduras
		NI	Nicaragua
		PA	Panama
		PE	Peru
		VE	Venezuela
2	NNn_%		Proportion of specified soil type (e.g. FRh) within SUID (e.g. BR214)
		ACh	*Haplic Acrisols*
		ANu	*Umbric Andosols*
		CMd	*Dystric Cambisols*
		CMe	*Eutric Cambisols*
		CMu	*Umbric Cambisols*
		FRh	*Haplic Ferralsols*
3	NNn_SQKM		area in km^2 of specific soil type having similar LGP, slope and elevation conditions as the considered ecosystem
4	SQKM_POLY		area in km^2 of SUID
5	%_NNn		Proportion within SUID of the specific soil type having similar LGP, slope and elevation conditions as the considered ecosystem

B – List of SOTER polygons with *Umbric Andosols* in Ecosystem 1.

SUID	ANu_%	ANu_SQKM	SQKM_POLY	%_ANu
CO46	50	46.644	1844.261	2.5
CO45	100	90.647	2119.586	4.3
CO26	60	258.348	1304.274	19.8
CO26	60	43.934	4717.854	0.9
CO26	60	345.672	4188.986	8.3
CO26	60	13.268	1238.945	1.1
CO26	60	561.612	3752.957	15.0
CO26	60	1.857	2152.604	0.1
CO26	60	237.848	2838.888	8.4
CO25	70	15.598	559.087	2.8
CO25	70	319.624	2664.838	12.0
CO23	70	1622.629	3985.493	40.7
CO23	70	721.043	5143.578	14.0
CO23	70	1804.455	25887.498	7.0
CO19	100	109.180	845.759	12.9
EC9	75	97.127	3254.943	3.0
EC21	70	480.561	4178.866	11.5
EC19	60	61.775	1117.851	5.5
EC16	70	0.448	174.620	0.3
	Total	13664.540	71970.888	19.0

Note: Extrapolation criteria: *Umbric Andosols* having LGP 1, slopes >10% and elevation 1400-2000 m

C – List of SOTER polygons with *Dystric Cambisols* in Ecosystem 1.

SUID	CMd_%	SQKM_CMD	SQKM_POLY	%_CMd
CO23	30	695.036	3985.493	17.4
CO23	30	308.117	5143.578	5.9
CO23	30	772.956	25887.498	2.9
CO37	60	3.183	315.539	1.0
EC10	85	182.391	7054.442	2.5
EC11	45	485.598	12060.793	4.0
PE36	40	56.794	81098.150	0.1
PE75	30	330.983	15980.062	2.0
PE76	50	144.484	3212.845	4.5
PE8	60	35.721	43750.582	0.1
VE16	100	16.427	4363.398	0.4
	Total	6046.953	202852.380	3.0

Note: Extrapolation criteria: *Dystric Cambisols* having LGP 1, slopes >10% and elevation 1400-2000 m

D – List of SOTER polygons with *Haplic Acrisols* in Ecosystem 2.

SUID	ACh_%	ACh_SQKM	SQKM_POLY	%_ACh
BR214	40	3270.524	13330.451	24.5
BR214	40	6031.555	23875.357	25.2
BR214	40	91.245	3528.621	2.5
BR214	40	5.265	16882.912	0.0
BR216	40	485.349	14804.281	3.2
BR216	40	1324.706	7632.532	17.3
BR216	40	376.757	1581.657	23.8
BR216	40	604.895	1988.488	30.4
BR216	40	780.331	2221.115	35.1
BR216	40	265.132	2204.323	12.0
BR216	40	321.136	1300.088	24.7
BR216	40	196.704	636.261	30.9
BR216	40	196.156	1942.968	10.0
BR217	40	33805.256	111437.610	30.3
BR218	15	14186.375	146531.909	9.6
BR219	50	2422.957	5194.175	46.6
BR219	50	1181.818	2735.509	43.2
BR219	50	260.840	583.389	44.7
BR219	50	747.116	1827.594	40.8
BR219	50	894.175	2171.964	41.1
BR221	15	3357.902	26210.920	12.8
BR221	15	1609.317	13325.612	12.0
BR221	15	307.112	2897.984	10.5
BR231	15	7948.051	58131.071	13.6
BR232	15	6884.714	47834.021	14.3
BR232	15	96.190	671.285	14.3
BR232	15	2570.246	19034.787	13.5
BR233	20	700.520	3852.709	18.1
BR234	70	1032.983	2068.871	49.9
BR235	35	2052.067	6888.682	29.7
BR235	35	2983.571	10532.018	28.3
BR236	60	3542.454	7984.244	44.3
BR236	60	2102.407	5035.326	41.7
BR237	40	1118.176	4244.333	26.3
BR237	40	1653.547	4975.541	33.2
BR240	15	2046.480	17404.746	11.7
BR246	70	148.271	1442.513	10.2
BR247	30	245.481	8479.677	2.8
BR248	70	39.117	2616.035	1.4
BR249	70	15.275	9659.079	0.1
BR260	30	92.661	3808.977	2.4
BR261	25	1144.670	8624.394	13.2
BR262	70	918.557	41375.108	2.2
BR264	50	1631.360	15215.293	10.7
CO51	65	3195.729	5893.184	54.2

CO63	70	29414.378	57283.353	51.3
CO8	60	29.311	3432.310	0.8
CO8	60	18524.983	41086.004	45.0
CO8	60	23636.702	44665.015	52.9
CO8	60	3776.876	7573.085	49.8
CO9	45	32970.767	106001.839	31.1
CO9	45	151.300	2273.702	6.6
CO9	45	109.689	380.778	28.8
EC24	30	344.265	3081.179	11.1
EC3	60	1467.185	4137.782	35.4
EC43	45	106.099	341.584	31.0
EC5	70	851.566	1750.141	48.6
EC8	40	1320.582	11225.396	11.7
GY12	20	7.695	18428.964	0.0
PE1	40	16649.929	46163.553	36.0
PE11	40	4609.613	13631.340	33.8
PE17	20	30.393	35186.474	0.0
PE18	60	69.148	9192.505	0.7
PE2	40	747.095	2394.315	31.2
PE2	40	2490.222	7696.495	32.3
PE21	60	1474.471	4345.698	33.9
PE4	40	5027.495	15949.768	31.5
PE4	40	1022.962	3279.490	31.1
PE5	40	8752.588	26590.767	32.9
PE6	40	11424.386	56218.041	20.3
PE70	20	0.941	9649.902	0.0
PE8	40	7821.836	43750.582	17.8
VE15	40	174.766	2905.396	6.0
VE77	40	96.209	843.603	11.4
VE78	65	16.627	6661.295	0.2
VE94	70	0.692	423.762	0.1
VE95	70	7.156	1282.110	0.5
Total		288013.077	1278443.842	22.5

Note: Extrapolation criteria: *Haplic Acrisols* having LGP 1 or 1', slopes <5% and elevation <300 m

E - List of SOTER polygons with *Haplic Ferralsols* in Ecosystem 2.

SUID	FRh_%	FRh_SQKM	SQKM_POLY	%_FRh
BR222	15	1466.001	10435.436	14.1
BR222	15	753.335	5311.940	14.2
BR222	15	80.248	563.915	14.2
BR237	60	1676.510	4244.333	39.5
BR237	60	2478.517	4975.541	49.8
BR244	60	7091.041	19066.269	37.2
BR244	60	3180.039	8687.200	36.6
BR249	15	3.271	9659.079	0.0
BR287	60	2110.066	4742.977	44.5
CO36	40	6935.077	25010.660	27.7
CO36	40	1824.791	5559.629	32.8
CO38	70	0.958	264.006	0.4
CO38	70	90.113	702.127	12.8
CO38	70	259.845	1897.413	13.7
CO41	40	7.601	3663.045	0.2
CO42	100	1043.385	100389.775	1.0
CO43	20	49.946	381.661	13.1
CO43	20	190.128	1120.026	17.0
CO43	20	154.663	877.917	17.6
CO43	20	131.722	1030.745	12.8
CO43	20	230.902	3944.103	5.9
CO43	20	360.910	3006.618	12.0
CO43	20	233.479	3306.603	7.1
CO44	40	644.660	2665.140	24.2
CO44	40	296.023	1211.186	24.4
CO51	35	1719.583	5893.184	29.2
CO63	30	12606.128	57283.353	22.0
CO64	45	4044.682	11867.462	34.1
CO8	15	7.326	3432.310	0.2
CO8	15	4630.783	41086.004	11.3
CO8	15	5907.232	44665.015	13.2
CO8	15	943.613	7573.085	12.5
CO9	25	18316.528	106001.839	17.3
CO9	25	84.037	2273.702	3.7
CO9	25	60.853	380.778	16.0
EC43	25	58.887	341.584	17.2
GY21	55	733.672	16511.194	4.4
GY5	65	82.139	12162.488	0.7
	Total	80488.694	532189.342	15.1

Note: Extrapolation criteria: *Haplic Ferralsols* having LGP 1 or 1', slopes <5% and elevation <300 m

F - List of SOTER polygons with *Dystric Cambisols* in Ecosystem 3.

SUID	CMd_%	CMd_SQKM	SQKM_POLY	%_CMd
GT155	15	2.723	4340.482	0.1
CR185	50	657.760	1320.837	49.8
CR210	40	12.480	170.340	7.3
CR210	40	16.326	240.190	6.8
PA210	40	15.280	601.893	2.5
PA210	40	4.727	64.570	7.3
PA210	40	0.340	51.232	0.7
PA210	40	0.382	36.072	1.1
PA210	40	0.178	53.597	0.3
PA210	40	14.894	828.520	1.8
	Total	725.090	7707.733	7.8

Note: Extrapolation criteria: *Dystric Cambisols* having LGP 1, slopes 0-5% and elevation <200 m

G - List of SOTER polygons with *Umbric Cambisols* in Ecosystem 4.

SUID	CMu_%	CMu_SQKM	SQKM_POLY	%_CMu
CR184	50	27.714	1869.761	1.5
PA69	100	49.418	243.967	20.3
PA82	80	20.658	863.249	2.4
	Total	97.790	2976.977	8.0

Note: Extrapolation criteria: *Umbric Cambisols* having LGP 4, slopes 15-30% and elevation <300 m

H - List of SOTER polygons with *Dystric Cambisols* in Ecosystem 4.

SUID	CMd_%	CMd_SQKM	SQKM_POLY	%_CMd
CR182	80	2.274	533.371	0.4
CR199	100	1.952	1660.739	0.1
CR206	80	2.825	1022.953	0.3
NI199	100	0.753	561.772	0.1
PA209	50	0.571	734.542	0.1
PA72	100	4.771	277.621	1.7
PA73	100	358.903	8909.777	4.0
PA80	70	386.807	4823.628	8.0
	Total	758.856	18524.403	1.9

Note: Extrapolation criteria: *Dystric Cambisols* having LGP 4, slopes 15-30% and elevation <300 m

I - List of SOTER polygons with *Eutric Cambisols* in Ecosystem 4.

SUID	CMe_%	CMe_SQKM	SQKM_POLY	%_CMe
CR184	25	13.857	1869.761	0.7
PA209	50	0.571	734.542	0.1
PA56	60	50.952	1787.279	2.9
PA57	40	0.829	1289.929	0.1
PA58	60	13.866	3245.329	0.4
PA59	50	147.574	3353.956	4.4
PA60	50	132.917	5866.494	2.3
PA61	40	56.784	2084.145	2.7
	Total	417.350	20231.435	1.7

Note: Extrapolation criteria: *Eutric Cambisols* having LGP 4, slopes 15-30% and elevation <300 m