Recovery of Degraded Pasture Areas and C-sequestration in Ecosystems of Tropical America

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Abstract: This research aims at identifying pasture and silvo-pastoral systems that provide economically attractive solutions to farmers and offer environmental services, particularly the recovery of degraded areas and C sequestration, in four ecosystems of Tropical America vulnerable to climate change. Soil C stocks, C contents in biomass, and socio-economic indicators were evaluated. Results of 5 years of research show that improved and well-managed pasture and silvo-pastoral systems can contribute to the recovery of degraded areas as C-improved systems.

Key-Words: Tropics, soil carbon stocks, tropical pastures, silvo-pastoral systems, climate change.

1 Introduction

The deforestation of native forests and the final conversion of these areas in pastures represent the most important change in land use in Tropical America (TA) in the last 50 years [12]. Close to 77% of agricultural lands in TA are currently under pastures [10] and, due to poor management, more than 60% of these lands are severely degraded [8]. Improved and well-managed pasture and silvo-pastoral systems represent an important alternative to the recovery of degraded areas and are a viable business activity for the producer [14]. Recent literature also suggests they have high potential for C sequestration [25]. The Kyoto Protocol to the United Nations Framework Convention on Climate Change [23] and subsequent agreements of the United Nations [15-22] suggest that the reforestation of areas currently under degraded pastures could have a negative impact on the economic production and social welfare of producers in TA, especially intermediate and small farmers. Therefore it is necessary to find sustainable alternatives that combine mitigation of poverty with economic production and supply of environmental services, especially C sequestration.

2 Objective

This article presents the findings of 4 years of research (2002-2005) that evaluated C accumulation in soil and plant biomass in a range of tropical pasture and silvo-pastoral systems and compared these results with those for native forest (positive reference) and degraded pasture (negative reference) in four ecosystems of TA that are susceptible to the adverse effects of climate change: eroded hillsides of the Colombian Andes; tropical rainforests in Colombia's Amazon region; sub-humid tropical forests along Costa Rica's Pacific coast; and tropical rainforests along Costa Rica's Atlantic coast. This study aims to identify the pasture and silvo-pastoral systems in each ecosystem that represent an alternative for farmers that is not only economically viable, but also environmentally beneficial, hence contributing to the recovery of degraded areas and to C sequestration. Previous works [1-6 and 13] report partial results that complement those of the present article.

3 Methodology

3.1 Experimental sites

Field research was conducted on producer farms at sites representative of each target ecosystem. Sites selected in the eroded hillside ecosystem of the Colombian Andes were Dovio (1900 m.a.s.l., 1043 mm annual precipitation, 18.5 ºC annual mean temperature, slopes between 45%-65%, moderately acid poor soils with pH 5.2-6.2) and Dagua (1350 m.a.s.l., 1100 mm annual precipitation, 21.5 ºC annual mean temperature, slopes between 25%-45%, poor acid soils with pH 5.0-5.8). In humid tropical rainforest ecosystem of Colombia's Amazon region, evaluations were carried out at two sites with differing topography: 'La Guajira' farm (flat topography, 400 m.a.s.l., 4500 mm annual precipitation, 32 ºC mean temperature, and poor, very acid soils with pH 4.0-4.6) and 'Pekín' farm (mild-slope topography, with <10% slope, 258 m.a.s.l., 4500 mm annual precipitation, 32 ºC annual mean temperature, and poor, very acid soils with pH 4.0-4.6). In Costa Rica's tropical rainforest ecosystem, evaluations were carried out in Pocora, on the Atlantic coast (200 m.a.s.l., 3500 mm annual precipitation, 29 ºC annual mean temperature, poor soils, less acid than those of Amazon region, with pH 5.0-5.6). Finally, for Costa Rica's sub-humid tropical rainforest, evaluations were carried out in Esparza, on the Pacific coast (200 m.a.s.l., 2500 mm annual precipitation with 5-6 months of drought, 27 ºC annual mean temperature, and soils similar to those of Pocora).

3.2 C assessment

The C accumulation in soil and plant biomass was assessed in pasture and silvo-pastoral systems already established (10-20 years) on commercial livestock farms. To achieve precise estimates, a sampling design that controlled the main sources of variation in C sequestration was used. Sources of variation were site conditions (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). Bulk density, texture, pH, total C, oxidable C, total N, P and CIC were analysed per soil sample, using international analytical methods [24] 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 [7] multiplying the dry matter/hectare of each component by 0.35 (to estimate C contents in pasture biomass) and by 0.42 (to estimate C contents in roots and in aerial biomass in silvo-pastoral systems). C accumulated in forest's aerial biomass was estimated using literature data on dry matter of aerial biomass of different types of forests in Colombia [11]. IDEAM cites 169.9 tons of dry matter of aerial biomass/ha for intervened Andean forest, and 207.7 tons/ha for intervened Amazonian forest. C in forest biomass was estimated multiplying those dry matter figures (in t/ha) by 0.42 according to CATIE [7]. To statistically compare the soil C-stock level among the different systems, C contents were corrected for bulk density and adjusted to a fixed soil weight using as reference value the sampling point of minimum weight in each ecosystem [9, 6]. Therefore, soil C-stock data in this article are expressed as tons of total C/ha at 1 m of soil depth-equivalent (t/ha/1m-eq).

3.3 Socio-economic evaluations

The economic benefit of investing in improved pasture and silvo-pastoral systems was evaluated by surveys and workshops with producers. Pertinent research findings are not presented in this article.

4 Results

Tables 1-3 present means per land use of soil C-stocks (adjusted to a fixed soil weight), C in pasture biomass, C in fine roots, C in thick roots, trunks and leaves (in forage banks and silvo-pastoral systems) and C in forest aerial biomass, together with the percentage that C accumulated in each component represents of the total C in the system for each land use under study. Table 1 presents the results obtained for Colombia's Andean hillsides, Table 2 those corresponding to the tropical rainforest of Colombia's Amazon region, and Table 3 those corresponding to Costa Rica's humid tropical rainforest. The tables present global descriptive statistics (N, mean, CV (%), LSD_{10}) and results of the statistical comparison of soil C-stocks among the different land use systems.

In all ecosystems studied (Tables 1-3) the native forest shows the highest levels of total C accumulated in the system (soil + biomass). However, differences in the ranking of the various land uses in terms of soil C-stocks were observed between ecosystems.

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

Site 1: Dovio

Land use system	Total C				
	Soil*	Pasture biomass**	Fine roots**	Thick roots, trunks, leaves**	System**
Native forest	231 a[2] (76%)	-	4.6 (1.5%)	69.7[3] (23%)	305.3
B. decumbens	147 b (97%)	0.9 (0.6%)	3.3 (2.2%)	-	151.2
Forage bank	131 c (86%)	-	4.3 (2.8%)	16.9 (11%)	152.2
Degraded pasture	136 c (97%)	0.5 (0.4%)	3.9 (2.8%)	-	140.4
N (sample points/sys)	24	40	24	8	
Mean, CV (%), LSD_{10}	161, 20, 18				

Site 2: Dagua

Land use system	Total C				
	Soil*	Pasture biomass**	Fine roots**	Thick roots, trunks, leaves**	System**
Forest (40 yrs old)	186 a[2] (72%)	-	2.6 (1.0%)	69.7[3] (27%)	258.3
Forest (15 yrs old)	155 ab (68%)	-	2.2 (1.0%)	69.7[3] (31%)	226.9
Natural reg of degr. pasture	142 b (97%)	0.5 (0.4%)	3.2 (2.2%)	-	145.7
B. decumbens	136 b (94%)	0.8 (0.6%)	8.3 (5.7%)	-	145.1
Forage bank	90 c (81%)	-	2.5 (2.2%)	18.4 (6.6%)	110.9
Degraded soil	97 c (98%)	-	1.6 (1.6%)	-	98.6
N (sample points/sys)	24	40	24	8	
Mean, CV (%), LSD_{10}	135,25, 30				

* Measured in t/ha/1m-eq.
** Measured in t/ha.
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 [11] multiplied by 0.42, according to CATIE [7].

Data from the Andean Hillsides ecosystem, Colombia (Table 1) suggest that at sites of higher altitude, lower temperature, steeps slopes, and relatively more fertile soils, the forest shows the highest levels of total C in the system (soil + biomass). Also the forest shows the highest levels of soil C-stocks (231 t/ha/1m-eq at site 1 of higher altitude, and 186 and 155 t/ha/1m-eq at site 2 of lower altitude), these means being statistically higher than those from improved *Brachairia decumbens* pasture (147 and 136 t/ha/1m-eq at sites 1 and 2 respectively) which, in turn, are statistically higher than those from a degraded pasture and a degraded soil (136 and 97 t/ha/1m-eq at sites 1 and 2 respectively).

Data from the tropical rainforest of Colombia's Amazon region, flat topography (Table 2) and from Costa Rica's humid tropical forest (Table 3) show a situation that differs from that of the Andean hillsides (Table 1) regarding levels of soil C-stocks. 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-stock levels (144, 138, 128, and 124 t/ha/1m-eq) that are statistically higher than those of the intervened native forest (107 t/ha/1m-eq).

A similar situation is observed in Costa Rica's humid tropical forest (Table 3) of warm lowlands, with a high precipitation of 3500 mm/year and poor acid soils, where improved pasture and silvo-pastoral systems of *Brachiaria brizantha* + *Arachis pintoi*, *Ischaemum ciliare*, *Acacia mangium* + *A. pintoi*, and *B. brizantha* show levels of soil C-stocks (181, 170, 165, 138 t/ha/1m-eq) statistically higher than those of the native forest (134 t/ha/1m-eq) and to those of a degraded pasture (95 t/ha/1m-eq).

On mild-slope topography, Amazonia (Table 2) the situation is different from the flat Amazon region. The native forest shows the highest soil C-stocks (181 t/ha/1m-eq) statistically higher than improved pasture systems (172 and 159 t/ha/1m-eq) which are, in turn, statistically higher than those found in a degraded pasture (129 t/ha/1m-eq).

Table 2. Carbon in soil and biomass. Tropical rainforest ecosystem, Amazonia, Colombia.[1]

Site 1: 'La Guajira' farm (flat topography)

Land use system	Total C				
	Soil*	Pasture biomass**	Fine roots**	Aerial biomass**	System**
B. humidicola	144 a[2] (96%)	1.9 (1.3%)	4.9 (3.2%)	-	150.8
B. humidicola + legume	138 b (95%)	2.1 (1.4%)	5.5 (3.8%)	-	145.6
Natural reg of deg pasture	134 b (97%)	1.3 (1.0%)	2.4 (1.7%)	-	137.7
B. decumbens + legume	128 c (97%)	1.2 (0.9%)	3.2 (2.4%)	-	132.4
B. decumbens	124 c (98%)	1.1 (0.9%)	1.8 (1.4%)	-	126.9
Native forest	107 d (54%)	-	5.0 (2.5%)	85.1[3] (43%)	197.1
N (sample points/ sys)	27	45	27		
Mean, CV (%), LSD_{10}	129, 10, 5				

Site 2: 'Pekín' Farm (mild-slope topography)

Land use system	Total C				
	Soil*	Pasture biomass**	Fine roots**	Aerial biomass**	System**
Native forest	181 a[2] (67%)	-	4.6 (1.7%)	85.1[3] (31%)	270.7
B. decumbens + legume	172 b (98%)	0.9 (0.5%)	2.4 (1.4%)	-	175.3
B. humidicola	159 c (97%)	1.1 (0.7%)	4.5 (2.7%)	-	164.6
Degraded pasture	129 d (97%)	0.9 (0.7%)	2.6 (1.9%)	-	132.5
N (sample points/ sys)	27	45	27		
Mean, CV (%), LSD_{10}	144, 11, 7				

* Measured in t/ha/1m-eq.
** Measured in t/ha.
[1] Results 2002-2005, C Sequestration Project- The Netherlands Cooperation CO-010402, Internal Publication No. 16. Dec 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 Amazonian forests in Colombia (IDEAM, 2006) [11] multiplied by 0.42 according to CATIE [7].

Data obtained from the humid tropical ecosystems (Tables 2-3) suggest that in warm, humid lowlands, with poor acid soils, with high nutrient recycling rates, improved pasture and silvo-pastoral systems adapted to these environments and well-managed by producers, show soil C-stock levels comparable or even higher than those from the intervened native forest. Therefore these systems play an important role in the recovery of degraded pasture areas because of their high C sequestration potential. On the other hand, estimates obtained on C accumulated by the native forest in its aerial biomass make it possible to quantify the severe potential loss of C when a native forest in these ecosystems is felled.

Table 3. Carbon in soil and biomass for each land use system. Humid Tropical Forest ecosystem, Pocora, Costa Rica.

Land use system	Total C				
	Soil*	Pasture biomass**	Fine roots**	Thick roots, trunks, leaves**	System**
B. brizantha + *A. pintoi*	181 a[2] (98%)	1.5 (0.8%)	1.5 (0.8%)	-	184.0
I. ciliare grass	170 a (97%)	1.7 (1.0%)	2.8 (1.6%)	-	174.5
A. mangium + *A. pintoi*	165 b (90%)	1.0 (0.6%)	4.4 (2.4%)	12.9 (7.0%)	183.3
B. brizantha	138 c (98%)	1.6 (1.1%)	1.8 (1.3%)	-	141.4
Native forest	134 c (60%)	-	4.0 (1.8%)	85.13 (38%)	223.1
Degraded pasture	95 d (95%)	1.6 (1.6%)	3.8 (3.8%)	-	100.4
N (sample pts/ sys)	24	40	24		
Mean, CV (%), LSD_{10}	150. 24, 14				

* Measured in t/ha per 1 meq.
** Measured in t/ha.
[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 humid tropical forests in Colombia [11] multiplied by 0.42 according to CATIE [7].

Data from the various ecosystems studied (Tables 1-3) show that soil C-stocks represents from the total C accumulated in the system between 54 and 67% in a native intervened tropical humid forest (Tables 2 and 3); between 72 and 76% in a native intervened Andean forest (Table 1); 90% in a silvo-pastoral system of *Acacia mangium* + *Arachis pintoi* (Table 3); between 81 and 86% in a forage bank under cutting (Table 1); and between 94 and 98% in pasture systems (Tables 1-3). 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 3). The C accumulated in fine roots accounts for 0.8%-5.7% across all land use systems, being the highest percentage observed in an improved *Brachiaria decumbens* pasture (5.7% in

Andean Hillsides, Table 1) followed by an improved *Brachiaria humidicola* + native legumes pasture (3.8% in the humid tropical forest of flat Amazonian region). C in pasture biomass accounts for 0.4%-1.6% (Tables 1-3).

5 Conclusions

The findings of these 4 years of research (2002-2005) on target tropical ecosystems suggest:

1. In terms of C accumulated in the total system (soil + plant biomass) the native forest presents the highest levels of all land uses in all ecosystems, followed by improved silvo-pastoral systems, improved pasture systems, natural regeneration of degraded pastures, and finally degraded pasture or degraded soils.
2. In terms of C accumulated in the soil, improved and well-managed pasture and silvo-pastoral systems show comparable or even higher levels than the native forest, depending on local climatic and environmental conditions.
3. The C accumulated in the soil accounts for a very high percentage of the total C of the system (between 54%-76% in native intervened forests, 81%-86% in forage banks under cutting, 90% in a silvo-pastoral system of *Acacia mangium* + *Arachis p*intoi, and 94%-98% in pasture systems).
4. Research results indicate that improved and well-managed pasture and silvo-pastoral systems should be regarded as attractive alternatives from the economic and environmental viewpoints, especially because of their capacity to recover degraded areas and their C sequestration potential.

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