Revista EIA, ISSN 1794-1237 / Año XII / Volumen 12 / Edición Epecial N.2/ Junio 2015 / pp. E47-E53
Publicación semestral de carácter técnico-científico / Escuela de Ingeniería de Antioquia —EIA—, Envigado (Colombia)

CARBON FIXING CAPACITY OF AMAZONIAN SOILS IN RELATION TO ITS DEGRADATION CONDITIONS

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ABSTRACT

Amazonian deforestation and transformation alert about their effects worldwide. One concern is the increase of the Carbon (C) levels emitted. Previous works have estimated the fixed C in Amazon forests without including the C stored in soils. Within soil, the organic carbon molecules are highly sensitive to degradation, affecting the natural capacity of soils to fix and store C. The present study evaluates the impact of degradation in the natural capacity of Amazon soils to fix C. Thirty five farms with different typology were selected in Caquetá department which hold the highest deforestation and soil degradation rates in the Colombian Amazon. Soil samples were taken from natural forest relicts, cropping areas and introduced pastures of the farms, in locations with high, intermediate and low soil degradation. Aerial biomass was estimated in pastures with different level of soil degradation. Changes in the labile C stock were estimated from the soil organic carbon and the microbial biomass using substrate induced respiration. Results showed that the main C pool is in the natural forest relicts and the crops of the farms, independently from the size or type of farm sampled. The hills with higher intervention showed the lowest soil C fixation capacities. The soil C fixation capacity was related with changes in the soil microbial composition where conserved soils store preferentially C as fungal biomass while degraded soils store C as bacterial biomass. These estimations contribute to establish the cost of sustainability and soil degradation in the Colombian Amazon.

KEYWORDS: Setting C; Amazonian Soils ; Degradation; Emotions.

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Historia del artículo:
Artículo recibido: 8-X-2013 / Aprobado: 27-VIII-2014
Disponible online: 30 de septiembre de 2014
Discusión abierta hasta diciembre de 2016

DOI: http:/dx.doi.org/10.14508/reia.2014.11.E2.47-53

CAPACIDAD DE FIJACIÓN DE C DE LOS SUELOS AMAZÓNICOS Y SU RELACIÓN CON SU ESTADO DE DEGRADACIÓN

RESUMEN

La deforestación y transformación de la Amazonia alertan sobre sus efectos en todo el mundo. Una preocupación es el aumento de los niveles de C emitidos. Trabajos anteriores han calculado el C fijado en los bosques amazónicos sin incluir el C almacenado en el suelo. Las moléculas de carbono orgánico en el suelo son muy sensibles a la degradación, afectando la capacidad natural de los suelos para fijar y almacenar C. Este trabajo evaluó el impacto de la degradación de la capacidad natural de los suelos amazónicos para fijar C. Treinta y cinco granjas con diferentes tipologías fueron seleccionadas en el Departamento de Caquetá, que posee las tasas más altas de deforestación y de degradación del suelo en la Amazonia colombiana. Las muestras de suelo fueron tomadas de relictos de bosques naturales, zonas de cultivo y pastos introducidos de las granjas, en lugares con alta, media y baja degradación de suelos. La biomasa aérea se calculó en los pastos con diferente nivel de degradación del suelo. Los cambios en stock C lábil se estimaron a partir del carbono orgánico del suelo y la biomasa microbiana mediante la respiración inducida por sustrato. Los resultados mostraron que el C pool se encuentra en los relictos de bosques naturales y en los cultivos de las granjas, independientemente del tamaño o tipo de granja analizada. Las colinas con una mayor intervención mostraron la más baja capacidad de fijación de C del suelo. La capacidad de fijación de C del suelo se relaciona con los cambios en la composición microbiana del suelo, donde en los terrenos conservados C es almacenado como biomasa fúngica, mientras que los suelos degradados almacenan C como biomasa bacteriana. Estas estimaciones contribuyen a establecer el costo de la sostenibilidad y la degradación del suelo en la Amazonia colombiana.

PALABRAS CLAVES: fijación de C; suelos amazónicos; degradación; emociones.

CAPACIDADE DE FIXAÇÃO DE C DOS SOLOS DA AMAZÔNIA E SEU RELACIONAMENTO COM SEU ESTADO DE DEGRADAÇÃO

RESUMO

O desmatamento e a transformação da Amazônia alertando de seus efeitos em todo o mundo. Uma preocupação é o aumento de níveis C emitidos. Trabalhos anteriores tem calculado o C fixando em florestas amazônicas excluindo o C armazenada no solo. As moléculas de carbono orgânico no solo são altamente sensíveis à degradação, afetando a capacidade natural do solo para fixar armazenar C. Este estudo avaliou o impacto da degradação da habilidade natural dos solos da Amazônia para fixar C. Trinta e cinco diferentes tipos fazendas foram selecionados em Caqueta, que tem as maiores taxas de desmatamento e degradação do solo na Amazônia colombiana. As amostras de solo foram retiradas de remanescentes florestais em áreas naturais, zonas de cultivo e de pastagem introduzidas nas fazendas em locais com alta, média e baixa gradação. A biomassa aérea foi calculada em pastagens com diferentes níveis de degradação do solo. As mudanças nos estoques C lábil foram estimados a partir de carbono orgânico no solo e a biomassa microbiana pela respiração induzida por substrato. Os resultados mostraram que o C pool é encontrado nos relictos das florestas naturais e plantações de agrícolas das fazendas, independentemente do tamanho ou tipo de fazendas analisadas. As ladeiras com maiores intervenções apresentaram a menor capacidade fixação de C no solo. A capacidade de fixação de C do solo se relaciona com alterações na composição microbiana do solo, onde os terrenos conservados armazenam C como biomassa fúngica, enquanto que os solos degradados armazenam C como biomassa bacteriana. Estas estimativas ajudam a estabelecer o custo da sustentabilidade e da degradação do solo na Amazônia colombiana.

PALAVRAS-CHAVE: Fixação C; Solos da Amazônia; A degradação; Emoções.

1. INTRODUCTION

The increase of C levels emitted from natural pulls considered as stable stocks until recently, alert about its effects worldwide. Some of the causes for the increasing emission of CO_2 and other warming effect gases are deforestation and soil degradation (Lal, 2007) . Later processes occur in the colonization frontier of the Colombian Amazon. For 2007, about 7% of the Colombian Amazon presented ecosystemic transformations mainly caused by the conversion of natural vegetation into pastures. Introduced pastures represents 98.9% of the total disturbed area of the region Murcia-García, *et al.*, 2007. These areas are mainly located in the Caquetá, Meta and Putumayo departments. From these, Caquetá holds the highest deforestation and soil degradation rates as a consequence of the increasing pastured areas for cattle ranching. The transformation of forested areas into pastured areas produces physical, chemical and biological changes to the soil (Carvalho, *et al.,* 2009). Withinsoil, the organic molecules are highly sensitive to degradation, affecting the natural capacity of fixing and storing C. Therefore, soil degradation decreases the contents of soil organic carbon and increases the CO_2 and other greenhouse gases emission (Carvalho, *et al.*, 2009 y Cerri, *et al.*, 2003). It is estimated that between 42 and 59% of soil organic C is lost with the transformation of forest to pastures or croplands (Cerri, *et al.,* 2003). Generally it has been affirmed that soil degradation is controlled mainly by abiotic variables such as nutrient availability, soil density, temperature, humidity and pH (Waldrop, *et al.,* 2000), excluding the importance of microbial communities. There is evidence that fungi and bacteria have different metabolic activities using in several ways the organic matter (Maia, *et al.,* 2010). This study evaluated the impacts that Amazonian soil degradation have on natural C fixing capacity, including effects on microbial biomass and microbial community composition.

2. MATERIALS AND METHODS

This work was conducted in the Caquetá department, located at 270-407 masl in the Colombian Amazon region. It has an average annual precipitation of 3800 mm and an average temperature of 25°C. Based on the Vegetation and land use maps of Amazonia, published by the Sinchi Institute (Murcia-García, *et al.,* 2007), the study area was selected in a corridor with a disturbance gradient from low disturbed areas to highly disturbed areas. A total of 35 farms located in various landscapes and with different typologies were selected. Differences in farm typology corresponded to differences in the productive activities developed. Most of the farms had pastures, croplands and forest relicts with different levels of intervention.

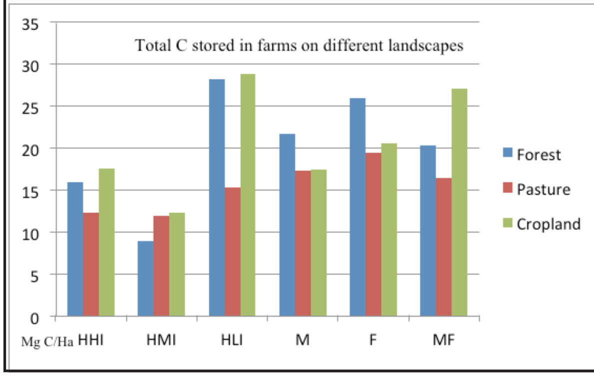
Aerial C biomass and soil C were evaluated in pastures, while soil C was evaluated in forest relicts and croplands in the farms. To estimate the aerial C biomass in the pastures, the level of pasture degradation was preliminarily estimated using quantitative characteristics (Sifuentes-Cortez, 2009). Plots of 1 x 1 m were used to collect the material, cutting the vegetation at the topsoil level. Vegetation samples were divided into *B. decumbens* grass and other plant species (herbs and weeds). Vegetal C estimation was obtained from C foliar content of the samples.

To determine the stored soil C, plots of approximately 1Ha were selected in the farms within forest, cropland and pasture areas. In these, five points were sampled at depths between 0 and 10 cm for microbial biomass evaluation and a sample of A horizon was obtained for physicochemical analysis. The physicochemical analysis was conducted by Agrilab soil laboratories in Bogotá city. The estimation of organic carbon in humic and fulvic acids was obtained by the GIEM research group of the Universidad de Antioquia in Medellín city. The organic carbon stock in soils was determined by the equation in which C (g/g) is multiplied by density (kg/m^3) and depth of the horizon(m) (Cerri, *et al.*, 2003 y Moraes, *et al.,* 1997).

The microbial biomass was estimated using the induced substrate respiration technique at 30°C with a gas chromatographer equipped with a temperature conductivity detector. The samples were incubated at 30°C for 3-5 hours checking the CO_2 emission rate. Microbial biomass was calculated from the equation: Cmic (mg C g-1 soil)= (mg of CO_2 Kg of soil) x 40,04+ 0,37 (Susyan, *et al.,* 2011 y Ananyeva, *et al.*, 2008). The basal respiration was determined using the same methodology used to estimate the induced substrate respiration but instead of a glucose a solution 100ul of sterile distilled water were used. The samples were incubated at 30°C for 24h. The results were expressed in mg CO_2 Kg^{-1} soil h^{-1}. Finally, the metabolic coefficient (qCO_2) was calculated as BR/CmiC= qCO_2 (mg CO_2-C mg^{-1} Cmic h^{-1}).

To estimate the relative populations of cultured fungal and bacterial in the samples, we repeated the last protocol but we added 100ul of Chloramphenicol (to inhibit bacteria) or 100ul of Nistanine (to inhibit fungi) according to the population we wanted to estimate. The samples were incubated for 4-6 hours before reading them at the gas chromatographer. The rate of inhibition of the microbial activity was calculated by the equation IAR= [(A-B)+(A-C)]/(A-D). Where A is the soil respiration (CO_2) produced with glucose; B is the soil respiration with glucose and Nistanine; C is the soil respiration with glucose and Chloramphenicol and D is the soil respiration with Glucose+Nistanine+Chloramphenicol.

Figure 1. Soil carbon stored under forest relicts, pastures and croplands in farms from different landscapes



3. RESULTS AND DISCUSSION

The aerial C accumulated in pastures showed that areas with high degradation stored less C as *B. decumbens* and significantly more as other weeds and herbs that contributed with less litter to the soil (**Table 1**).

The highest fixed C in soils occurred in the forest relicts and croplands and not in the pastures, independently of the size or type of farm sampled (**Figure 1**), of which forest relicts and croplands areas had better C soil fixation capacities.

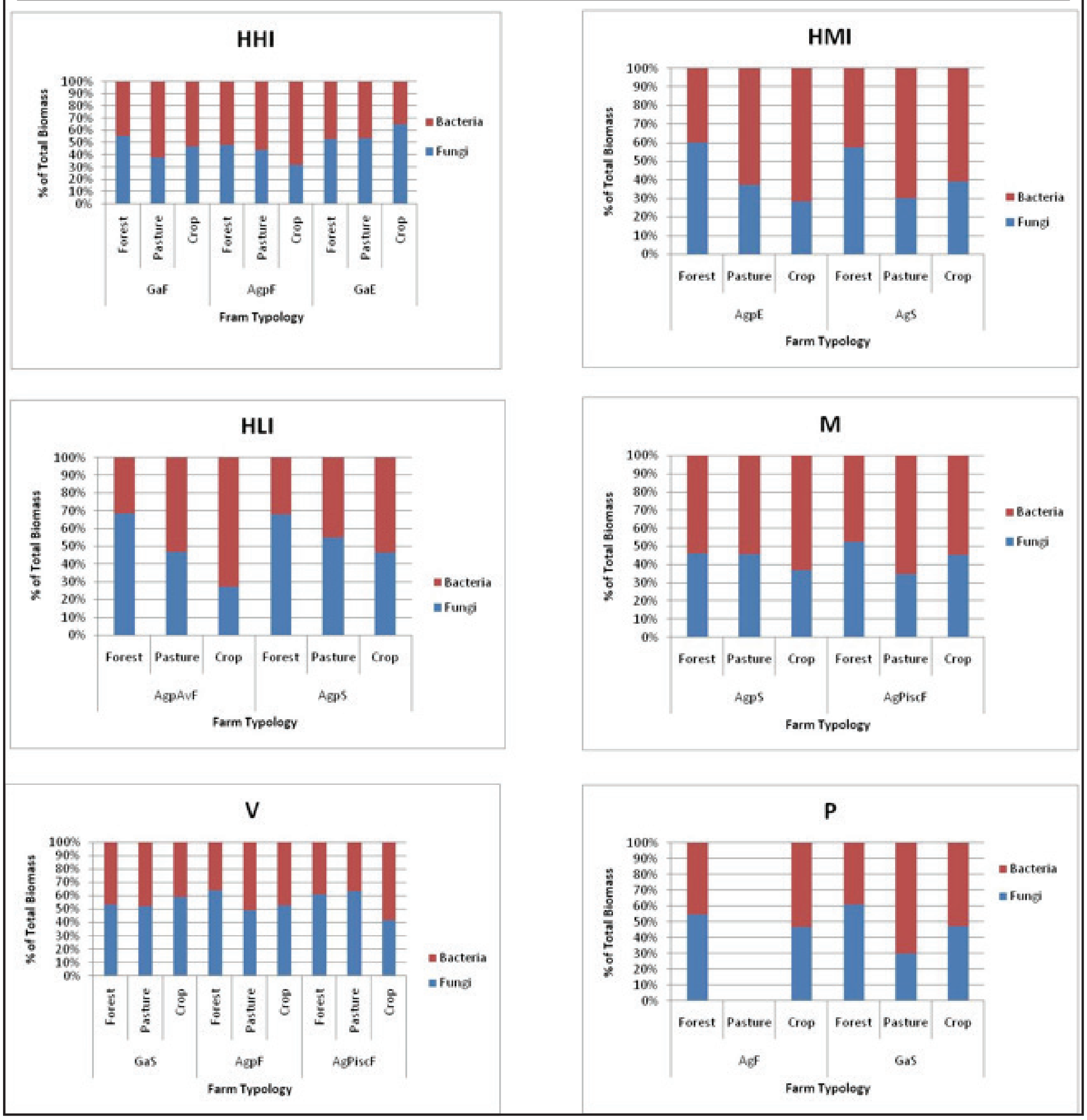
The main soil C deposits occurred in hills with low intervention (HLI) and floodplains. Results are explained as a consequence of the C inputs those landscapes receive: HLI also presented the higher quantities of litter accumulated over the soil and floodplains receive sediments rich in C with each periodical flood. The hills with moderate intervention (HMI) presented the lowest soil C stocks. This tendency was related directly with the level of soil degradation: the highest soil degradation has the lowest C fixing capacity the soil. Similar results were found in the Brazilian Amazon where the net productivity of the ecosystem depended of its level of degradation (Grant, *et al.,* 2009).

In hills with high intervention (HHI), cattle ranching farms with commercial models of production presented higher soil C stocks. Their capacity to fix C was not related

Table 1. Aboveground C storage in pastures with different levels of degradation

		DEGRADATION	INTERVENTION		
			HIGH	MODERATE	LOW
Alive biomass	*B. decumbens*	LOW	1.86±0.08 a	1.88±0.12 a	0.95±0.21 a
		MODERATE	0.67±0.04 b	0.89±0.07 b	0.67±0.06 b
		HIGH	0.05±0.01 c	0.08±0.01 c	0.79±0.12 c
	Others	LOW	0.55±0.04 b	0.20±0.03 c	0.65±0.14 c
		MODERATE	1.16±0.05 a	0.99±0.07 b	0.70±0.06 b
		HIGH	1.22±0.05 a	1.43±0.09 a	1.41±0.21 a
Death biomass		LOW	0.26±0.01 a	0.83±0.11 a	0.98±0.21 a
		MODERATE	0.37±0.07 a	0.38±0.05 b	0.41±0.04 b
		HIGH	0.22±0.02b	0.15±0.02 c	0.61±0.09 a

Figure 2. Soil fungi and bacteria community composition of farms in different landscapes



to the level of soil degradation. Instead it was more related with the capacity of farm owners to apply fertilizers and other amendments to sustain their productive systems when soils cannot maintain them with its natural fertility. Similar results were found in the Brazilian Amazon with increases of soil organic C between 1 to 8% in highly degraded pastures (Carvalho, *et al.,* 2009).

The most representative farm typology on HHI is the familiar cattle ranching farm which is the one that has less soil C fixation capacity. The small cattle producers do not have the same economic capacity than big cattle producers to buy prepare and apply amendments in their farms. That is why they experiment more concern when soil degradation symptoms appears in their farms. In these cases, the most feasible economic alternative to those small producers is the forest logging to establish new pastures while the degraded pastures are abandoned for natural restoration. It has been demonstrated that this system is economically effective for small producers with limited resources, however they will require around 12 to 14 years to completely recover the degraded pastures and their soil C fixing capacity (Feldpausch, *et al.,* 2004). That is why deforestation continues.

The difference between the landscape with the highest soil C stock (72.42 Mg C/Ha in HLI) and the landscape with the lowest soil C stock (33.14 Mg/Ha in HMI) is 39.28 Mg C/Ha which is a difference of 45.76% between the two systems. If we transform the soil C loose occurred in HMI into money, using the commercial value given by the Chicago Stock Exchange (14.38€ Ton of fixed C/Ha constant prices at December 2012), the land of the small producers is not only degraded but also costs 564,84€ less per hectare.

Changes in land use in the Amazon region produce a depletion on soil fixed C related also with changes in the soil microbial composition. Our results indicate that conserved soils store C principally as fungal biomass while degraded soils stored C as bacterial biomass (**Figure 2**). Similar results were found in Californian soil where fungal biomass represented about 60-74% of the microbial community of forested soils while fungi represented less than 60% of microbial community in cropland soils (Carvalho, *et al.*, 2009). These results could be explained by changes in the content, quality and properties of the organic matter (Moraes, *et al.*, 1996) as well as changes in the cycles of soil mineralization and humidification that are reflected in a reduction of the soil capacity to maintain its fertility.

Forward results help to understand better the process of soil degradation and stimulate researchers to search for new alternatives of production on the Amazonia that could diminish deforestation and prevent soil degradation and its additional consequence, the emission of C stored in the forest and soil before.

4. CONCLUSIONS

The soil C fixation capacity of Amazonian soils was affected by the type of economic activity of each farm and the level of soil degradation. High soil degradation was related with a reduced capacity of soil to fix C. The microbial communities are highly sensitive to those soil changes. High levels of degradation favored the increase of bacterial communities and depleted the fungal communities, acting as a soil quality indicator. These estimations contribute to understand better the soil degradation process and to establish the cost that soil degradation has in the Colombian Amazon.

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Peña-Vanegas, C.P.; Mendoza-Olmos, E.R.; Cardona-Vanegas, G.I.; Betancurt-Parra, B.E.; Garzón-Gómez, M.T. (2015). Carbon Fixing Capacity of Amazonian Soils in Relation to its Degradation Conditions. *Revista EIA*, 12(E2) junio, pp. E47-E53. [Online]. Disponible en: http://dx.doi.org/10.14508/reia.2015.12.E2.47-53.