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Changes in soil organic carbon after burning in a forest-savanna edge

Cambios en el carbono orgánico del suelo después de una quema al borde de una savana forestal

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Abstract

Soils are one of the largest terrestrial pools of carbon, yet there is still little understanding of spatial variability for ecosystems in the tropics. Fire plays an important role in Neotropical savannas ecosystems and significantly contribute to global greenhouse gas (GHG) fluxes. Nevertheless, the impacts of burning on soil carbon is still uncertain in Latin America. We compared soil organic carbon (SOC) in the first 20 cm depth in savannas in pre and post fire conditions along a forests-savanna edge typically present in these landscapes of the northern South America. We established 8 transects of 20 m longitude along the border with $1m^2$ plots sampled every 4 m. SOC pre-disturbance was on average 1.794% (±SE 0.043) and the minimum value found (1.08%) was registered 6 months after the burning. Our results show that both the influence of the distance to the edge and the time of burning affect negatively the SOC and also there is a significant interaction between both variables. Our results provide improved estimates of the effect of fire on soil carbon stocks and its highly dynamic nature. We believe these finding will be a step to help better estimate GHG in this type of heterogeneous landscapes. Further it provides a tool for understanding C dynamics under a climate change context with predicted increased fire frequency, extent and severity.

Key words: SOC, fire, edge influence, disturbance, carbon cycle, Colombia.

Resumen

Los suelos son una de los mayores reservorios terrestres de carbono, sin embargo, todavía hay poca comprensión de su variabilidad espacial en los ecosistemas tropicales. El fuego juega un papel importante en los ecosistemas de sabanas neotropicales y contribuye significativamente a los flujos de gases de efecto invernadero (GEI). A pesar de ello, los impactos derivados de las quemas de carbono en el suelo son todavía muy inciertos en América Latina. En este estudio se comparó el carbono orgánico del suelo (COS) en los primeros 20 cm del suelo en las sabanas de la Orinoquía en Colombia en condiciones previas y posteriores a la ocurrencia de una quema a lo largo de un borde en la interfase bosques-sabana presente en estos paisajes del norte de Sudamérica. Se establecieron 8 transectos de 20 m de longitud a lo largo del borde entre el bosque y la savana y se crearon parcelas de $1m^2$ muestreadas cada 4 m. El COS en transectos pre-perturbación fue en promedio de 1.794% (± SE 0.043) y el valor mínimo encontrado (1.08%) se registró 6 meses después de la quema. Nuestros resultados muestran que el SOC es superior en el interior del bosque y que existe tanto una influencia de la distancia desde su borde y del tiempo desde la quema que afecta al COS. También hay una interacción significativa entre ambas variables. Nuestros resultados proporcionan valiosa información para mejorar las estimaciones de los efectos del fuego sobre las existencias de carbono en el suelo y ayudarán a una mejor estimación de GEI en este tipo de paisajes heterogéneos. Además se proporciona una herramienta para la comprensión de la dinámica del carbono en un contexto de cambio climático con el posible aumento de la frecuencia de incendios, extensión e intensidad de estos.

Palabras clave: COS, quema, influencia del borde, perturbación, ciclo del carbón, Colombia.

Introduction

Being an important part of the total carbon stored in tropical ecosystems, globally soil carbon makes up more than half of the carbon stored in forests. It is considered the second largest C pool after the ocean (Stockmann *et al.*, 2013) and therefore has a key role in the C global cycle. Although it has been less often quantified than other carbon pools in particular in the tropics (Sierra *et al.*, 2007) there are some estimates of the soil organic carbon capacity of the world soils for major global biomes. Globally over 54% of the organic C is stored in the first meter of soils and about 26% in the top 20 cm (Stockmann *et al.*, 2013).

Tropical grasslands and savannas soils are estimated to contain up to 264 Gt C in the first meter in comparison to the 213 Gt C for tropical forest soils (Stockmann *et al.*, 2013). The savannas of the neotropics represent significant sources of exchange of CO_2. SOC stocks are affected by climate and ecosystems conditions that can affect fluxes and increase the release of C from soils through several mechanisms i.e. changing net primary productivity, microbial activity or organic matter inputs to soil and is also influenced by processes such as erosion that facilitates lateral fluxes of carbon (Stockmann *et al.*, 2013; Vargas, Paz & de Jong, 2013). Species composition and community structure influence as well the amount of SOC and as such land use land cover changes can also strongly influence total C stocks in soils (Assad *et al.*, 2013; Berenguer *et al.*, 2014; Stockmann *et al.*, 2013) pastures and crop-livestock systems (CPS. In recent years, soil use change and disturbances such as fire have transformed these ecosystems and have currently converted them to a source of CO_2 emissions to the atmosphere (Berenguer *et al.*, 2014; Mouillot & Field, 2005) although the estimates of the effects on soil carbon stocks are still under discussion (Cerri *et al.*, 2007; de Blécourt, Brumme, Xu, Corre & Veldkamp, 2013) for which the impacts on soil carbon stocks have hardly been studied. In montane mainland southeast Asia, monoculture rubber plantations cover 1.5 million ha and the conversion from secondary forests to rubber plantations is predicted to cause a fourfold expansion by 2050. Our study, conducted in southern Yunnan province, China, aimed to quantify the changes in soil carbon stocks following the conversion from secondary forests to rubber plantations. We sampled 11 rubber plantations ranging in age from 5 to 46 years and seven secondary forest plots using a space-for-time substitution approach. We found that forest-to-rubber plantation conversion resulted in losses of soil carbon stocks by an average of 37.4\u00b14.7 (SE.

Neotropical savannas are present in heterogeneous landscapes with forests embebbed into a matrix dominated by savannas. The ecological conditions of the forest-savanna interphase are or particular interest giving the abrupt nature in most cases of boundaries between two very distinct vegetation forms, their dynamics and the role that soils may play (Warman, Bradford & Moles, 2013). Fire plays a critical role in fire prone vegetation in South America stabilizing the boundary between tropical forests and open vegetation such as savannas (Hoffmann *et al.*, 2009)primarily determined by feedbacks with fire. Vegetation-fire dynamics in each of these vegetation types are largely determined by the influence of the vegetation on fire behavior, as well as the effects of fire behavior on tree mortality, topkill (defined here as complete death of the aerial biomass, regardless of whether the plant recovers by resprouting. It has been recently pointed out that there is a lack of field data on the depletion of carbon stocks depending on the type, intensity and frequency of disturbances (Aguiar *et al.*, 2012; Berenguer *et al.*, 2014). Some soil characteristics such as soil moisture or soil chemistry have been studied in abrupt boundaries (Warman *et al.*, 2013) but there is still much uncertainty on aspects such as the potential influence that the forest edge might have in the soil carbon stocks and specially in the interaction with disturbances such as fire.

Fires mainly occur in northern South-America during a dry season lasting from December to early April (Armenteras-Pascual *et al.*, 2011; Armenteras, Romero & Galindo, 2005). In this study we collected field data on SOC for pre and post disturbance conditions in a forest-savanna boundary. The aim of this study is to quantify the effects of fire and the distance from the forest edge on the SOC in savannas of northern South America. Specifically we asked three questions, first a) what is the influence of the distance to the forest on the SOC of savannas?, second b) how does the SOC of savannas change after the fire season, and finally c) is there an interaction between the distance to the forest edge and the timing of burning on the SOC of savannas?

Materials and methods

Study area

The study area is located in the Colombia part of the Orinoco basin, in the Vichada region, in a natural reserve called Serranías de Casablanca (size 438ha), municipality of Cumaribo. This locality comprises well-drained high plains (~300 m) savannas and gallery forests. The locality constitutes an ecotone between the southernmost distribution of the natural savannahs of the Colombian Llanos and the Amazonian rainforest. The reserve is located 10 km from the Cumaribo urban center, on the Cumaribo-Villavicencio road and is surrounded by two indigenous reserves and smallholders (Figure 1). The region has experienced extraordinary fire-mediated deforestation in tandem with aggressive expansion of industrial agriculture for commodity markets (Romero-Ruiz, Etter, Sarmiento, & Tansey, 2010).

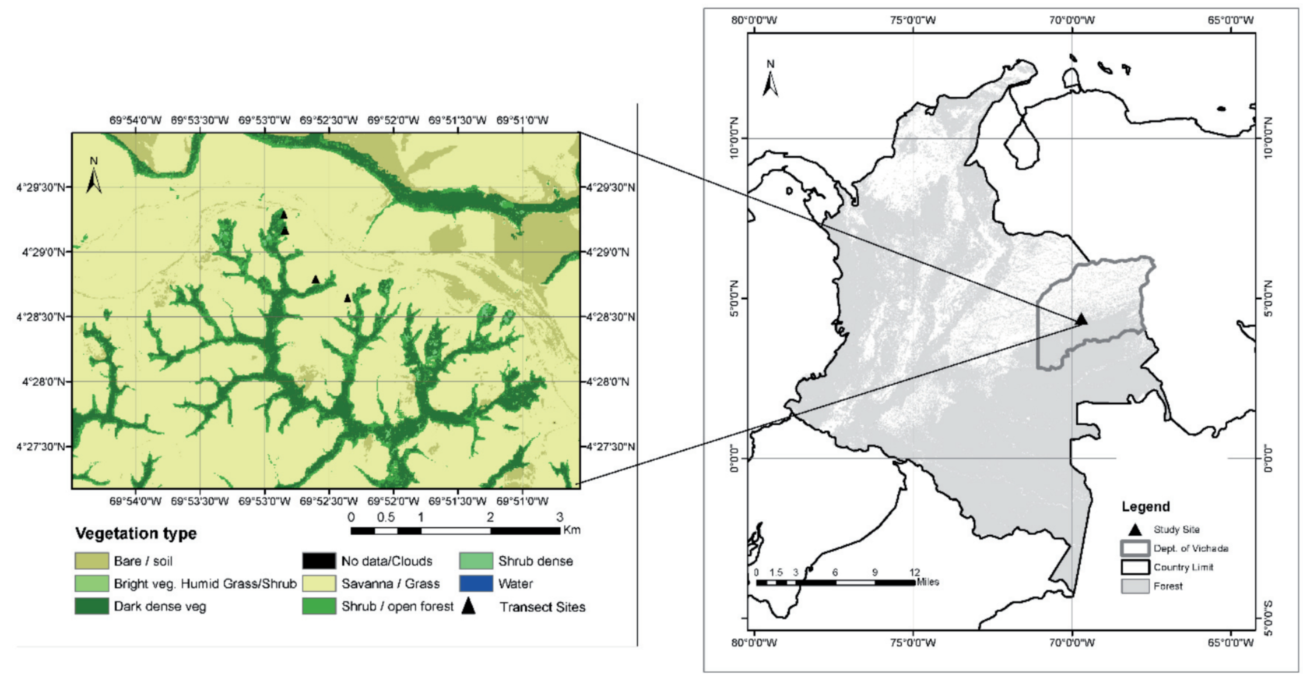

Figure 1. Vegetation in the study area, location of sampling sites

Annual rainfall for the region is on average 1500-2500mm, but local rainfall patterns are unimodal with rainfall between April and October, with a peak around in June and July. Temperature averages 28°C, with maxima rising up to 35°C. The landscape is mainly dominted by natural savannas with dominance of *Trachypogon sp.,* with areas of open savannas (Figure 2).

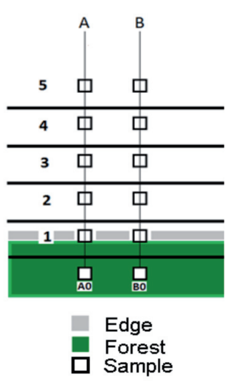

Figure 2. Transect design

Approximately 120 ha of the nature reserve are gallery forests. Predominant soils in *Trachypogon* savannas are well drained acid soils, generally chemically poor such as Ultisols and Oxisols (Instituto Geografico Agustin Codazzi –IGAC, 1988). The soils of the high plains are the oldest soils of the eastern plains of Colombia, in their stable flat-convex areas are oxisols. The parental material consists of ancient alluvial sediments, which in some areas were subjected to intense erosion and are located at an altitude of 100 - 150 m.a.s.l. The characteristics of these soils depend on the position they occupy within the landscape (IGAC, 1988).

These soils are strongly influenced by the weathering associated not only to the high temperatures but also the seasonality of the rainfall, as consequence soils are low in P, poor in organic matter, nitrogen and other exchangeable gases (López-Hernández, 2012).

Sampling design and statistical analysis

We selected 4 sampling sites where we established two transects of 24 m in each one for a total of 8 transects. A soil sampling plot of 1 m^2 was installed every 4 m for each transect, the first plot inside the forest (Figure 3). A soil sample of the first 20 cm depth was collected for each plot at three different moments of time. First sampling was undertaken in March 2015 at the end of the dry season, we call *this pre disturbance* (unburned) period. The day after the first samples were collected, we set a controlled fire in the sites and we sampled again the soil once the fire was put off for all plots in savannas, we call this time *post-burned0*. Finally six months later, in September 2015 during rainy season we came back and sampled all plots post disturbance, we call this timing *post_burned6* (6 months after the initial burning). We had a total of 136 samples.

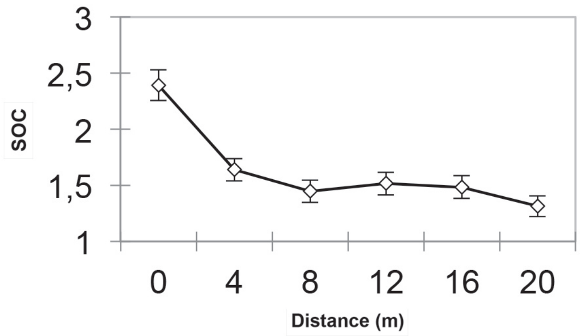

Figure 3. Mean values (± SE) of soil organic content (SOC, %) for the 6 distances from the forest edge.

Soil carbon concentration was measured using the Walkley-Black titration method (Walkley & Black, 1934), all the analysis were performed at the Soil laboratory of the Universidad Nacional de Colombia.

Finally, the influence of the independent variables on the SOC was analyzed using a two factor ANOVA with the software Xlstats-Addinsoft®.

Results

The average percentage of SOC (Figure 3) found in the soils pre-disturbance was of 1.794 (±SE 0.043), 1,576 (± SE 0.035) in the post_burn0 timing and the post_burn6 period presented a mean value of 1.525 (±SE 0.036). The maximum value of SOC found was of 3.97% in the pre-disturbance period for the forest plots and the lowest 1.08% in the post_burn6 at distance 8.

There is a significant effect of all distance, period of analysis and the interaction of both on SOC, being distance the most influential variable (F=7.285), p<0.001. (Table 1) (Figures 4, 5).

Table 1. Effects of distance and time on the soil organic content (SOC)

Source	DF	Sum of squa-res	Mean squares	F	Pr > F
Model	17	10.391	0.611	7.285	< 0.0001
Error	126	10.572	0.084		
Distance	5	7.207	1.441		< 0.0001
Time	2	0.632	0.316	3.765	0.026
Distance*Time	10	2.552	0.255	3.042	0.002

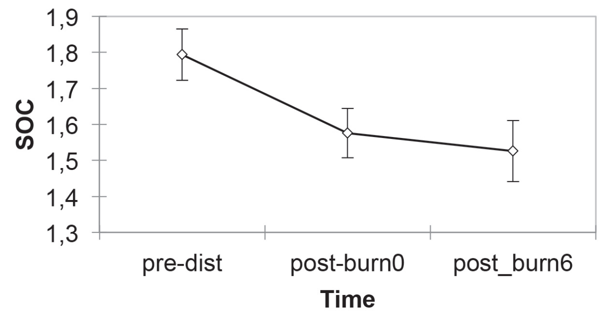

Figure 4. Mean values (± SE) of soil organic content for the 3 time periods (pre-dist, post_burn0, post_burn6).

There is an abrupt reduction of SOC between the forest plot and the first savanna plot sampled. The post hoc test revealed that the differences are indeed between the distance 0 and the rest of the samples (Fisher, p<0.05). On the other hand regarding the time the difference is between the pre-disturbance period and the post_burn6 (Fisher, p<0.05), but not between the pre-disturbance period and the post_burn0 (Fisher, ns, p=0.056), neither between both post-burn0 and 6 periods (Fisher, ns, p=0.486).

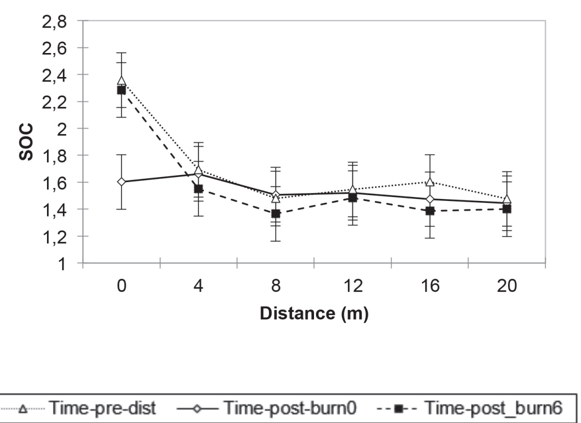

Figure 5. Mean values (± SE) of soil organic content for the 6 distances from the forest edge for all 3 periods of time.

Discussion

Carbon in soil organic matter is an important indicator of soil fertility because of its relationship with the chemical, physical and biological properties of soil linked to its quality, sustainability and productive capacity. It is a biophysical Indicator for desertification and soil degradation and is an important component of the global C cycle. Despites the fact that savannas are present in poor nutrient depleted soils by the highly seasonality of rainfall, these ecosystems are immersed in heterogenous landscapes with key production areas where agriculture activities are widely present but also with extensive areas of riparian or gallery forests. Soils under forest cover in this region have more organic matter content and thus also a higher capacity for water retention that soils more exposed under grass type vegetation.

In areas of savanna subject to burning, the contents of soil organic carbon are lower than in the soils of the forest edge given the vegetation present, the land use and also due to the disturbance. This is reflected in our results given the strong influence of the distance 0 or sample corresponding to soil under forest cover. This is partly due the lower content of organic matter and nutrients the savanna soil naturally gets. In addition is also influenced by the transfer of nutrients into the atmosphere in the form of gases and ash that reduces some inputs of organic carbon to the soil of the savanna. Not much information is available on the stocks and flows of the SOC in the savannas particularly with respect to the global level estimates, but our study brings some information to the knowledge of the most northern South American savannas.

Regarding forest soils, not only there is more organic matter content but also a more humid understory since forests tend to benefit the accumulation of water by the hydrophilic qualities of organic matter in direct relation to the edge effect (Hoffmann *et al.,* 2009). There has been some discussion of the transition point between the highly flammable savanna and the less flammable forest, this point is considered as the threshold of fire suppression. (Ryan, Williams, & Grace, 2011). The existence of this threshold results usually is when the cover of C4 grasses is no longer enough to feed the fire (Hoffmann *et al.,* 2012). The substitution of one vegetation for another implies the existence of a threshold for the passage of a pyrophasic to a pyrophilous system, but apart from the theoretical elaborations there are few concrete results (Silva, 2013).

Fire experimental studies are rare in Colombia, not only because of the costs and willingness to set fire but also the risks involved for escape fires. Nevertheless, advances like the one presented in this study contribute to the progress of knowing the effect of burning in the stock of SOC at the boundaries between savannas and forests. Our results indicate that plots were significantly different in SOC between pre disturbance unburnt period and post burn, although a recovery on SOC is expected associated to the growth of the graminea in the 6 months period after the burnt, we could not detect this given the short time frame analysed. It has been discussed that the soil can act as a source or reservoir C but depending on the soil management and there is a need of a longer time frame monitoring of C content in the soils and its effect on diversity. Further other variables that were not included in this study might also affect the intensity of the fire and this the effect on SOC (i.e. wind, fuel moisture, etc). Indeed some other important effects of fires are post fire changes related to the removal of mulch, plant residues, soil biological activity and nutrient availability. Even the soil use and its intensity is a factor that has yet to be studied in these savannas. For instance burning might increase pasture productivity in the short term but in the long long-term sustaining repetitive fires will eliminate plant cover and reduce the replenishment of the substrate to the soil, resulting in changes in the carbon and nitrogen balance of the system, which may eventually decrease the future nutrient supply for the pasture.

Finally, longer timeframe studies are needed to better understand the carbon and perturbation dynamics in the interface between the gallery forests and savannahs in this part of the world. Further, it is necessary to study not only the stock but also look carefully into carbon fluxes to have a better approximation to the annual carbon cycle of the region.

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