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BURNING OF PASTURE IN AMAZONIA: SHORT-TERM CHANGES IN SOIL CARBON STOCKS

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ABSTRACT

The effect of burning on release and stock of soil carbon in a 7-year-old pasture in Brazilian Amazonia was studied over a series of short time periods. Measurements were made in the pasture before the burn (pre-burn) and at 7, 120 and 210 days after the burn (post-burn) through the rainy and dry seasons and in adjacent primary forest (control). The carbon stock 210 days post-burn (20.2 t C. ha-1) was significantly lower than the other values observed, with the exception of the stock 7 days post-burn (23.4 t C. ha-1) (P<0.01(1),4,67, SNK test). Carbon stocks at the other sampling dates did not differ significantly from each other. A loss of 2.6 t C. ha-1 between the pre-burn (26.0 t C. ha-1) and the 7-day post-burn carbon stocks in the top 20 cm of forest-equivalent soil was not statistically significant, nor do the stocks at these two times differ significantly from that under primary forest (25.3 t C. ha-1). Carbon stored in the soil at 120 days post-burn (29.6 t C. ha-1) did not differ from the primary forest and pre-burn pasture. Seasonal oscillation of soil carbon stocks is apparent in the pasture soil, and, until the rainy season is past, this effect is capable of masking the effect of burning. The results suggest that the losses of carbon by burning and mineralization are greater than gains from humification of roots and plant remains, but the cumulative effect of these imbalances only becomes apparent after a certain time (in this case 210 days) has passed. Soil carbon in Amazonian pastures appears to be lost in small quantities over time under tropical management pratices.

Keywords: soil carbon, Amazonia, burning, fire, pastures, organic matter..

INTRODUCTION

Deforestation in Brazilian Amazonia makes a significant contribution to global emissions of gases such as CO_2, CH_4, CO, N_2O and NO_x (12 , 13, 14). Most of these emissions are through burning and decay of forest biomass. Gas releases from the soil also play a role, but the magnitude, and even the sign, of the net flux of soil carbon in converted areas is a subject of debate (17). Among the reasons for uncertainty is the importance of short-term changes in soil carbon in interpreting information on the size of carbon stocks (and, by inference, the magnitude of fluxes).

Of the 5 x 10^6 km^2 in Brazil's nine-state "Legal Amazon" region, 4 x 10^6 km^2 were forested prior to the arrival of Europeans in Brazil in 1500 (18). Of this "originally forested" area, 569 x 10^3 km^2 (14.2%) had been cleared by 2000, almost 80% of this clearing having taken place since 1970 (6 , 15). Prior to the changes in cleared parts of the region, soils under the original vegetation (including savanna areas) in the Brazilian Legal Amazon to a depth of 1 m contained 47 Gt C, of which 21 Gt C (45%) were in the top 20 cm (24). Considering the carbon stock between 1 and 8 m depth increases the total stock by a factor of approximately 4.3 (25). This implies that the soil to eight meters depth

in the Legal Amazon contained (prior to changes in the portion of the region that is now cleared) a total stock of soil carbon of 202 Gt. Isotopic evidence indicates that up to 15% of the deep soil (1-8 m depth) carbon stock turns over on annual or decadal time scales, and that the loss of deep roots by replacement of forests with pastures could release substantial amounts of carbon over time scales as short as a decade (25). Clearly, even small percentage changes in these carbon stocks would translate into fluxes large enough to be climatically significant, indicating the importance of reducing uncertainty concerning the amount, and even the direction, of soil carbon changes resulting from deforestation. The Intergovernmental Panel on Climate Change (IPCC) has so far not encouraged inclusion in the national inventories now being compiled under the Framework Convention on Climate Change (FCCC) of carbon loss from soils under cleared tropical forests (21).

Sequential measurements over short intervals (< 1 year, for example), which identify the effect of burning on the dynamics of soil carbon, need to be taken together with chronosequences over long periods if we are to understand the causes and consequences of burn effects. With this in mind, we accompanied the behavior of soil carbon in the surface layer (0-20 cm) in a a 7-year-old Amazonian pasture, with measurements before the burn and at 7, 120, and 210 days after the burn. This was an attempt to understand the dynamics of carbon release from the soil to the atmosphere (processes of loss and of replenishment) through the action of fire over short time intervals and as affected by climatic seasonality.

MATERIAL AND METHODS

Choice of Experimental Area

Our study site was centered on Vila do Apiaú (2o 33' 11" N ; 61o 18' 27" W), the administrative headquarters of a colonization area located 112 km southwest of the city of Boa Vista, Roraima, Brazil. The climate is classified as "Ami" under the Köppen system (tropical with a dry season), with a mean annual precipitation of 1900-2000 mm (22 , 27). The peak rainfall is from May to August, while the dry season lasts from December to March (2). In general the elevation is 100-150 m above mean sea level, with the exception of the Serra de Mucajaí (± 800 m).

Our experiment was set up on a red-yellow podzolic soil (Ultisol) widely associated with red-yellow latosol (Oxisol) (5). Together, these two soil types cover 45.1% of Brazilian Amazonia (24). By definitions of the Brazilian Institute of Geography and Statistics (IBGE), the original vegetation in the study area is a contact zone between dense forest (shade-loving: Ds) and a non-dense forest (seasonal/shade-loving forest: ON) (20). The site chosen for the study was an agricultural lot with a 7-year-old pasture of *Brachiaria humidicola* (Amazonian kicuiu grass). This is representative of the settlement area at the time of fieldwork. Previously the pasture had been burned three times: once on the initial conversion of the forest and twice in reburns. The third reburning (used by us), was conducted by the lot owner in March 1993 as a means of removing the invading weeds three years after the previous burn.

Soil Sampling

The samples were taken from the surface layer of the soil (0-20 cm). This layer stores 42-45% of all carbon in a 1-m profile (7 , 11). In addition, most of the short-term dynamics of organic carbon is restricted to this layer in most tropical soils (28).

In addition to sampling in the pasture, samples were also taken in the adjacent forest so that the latter could serve as part of the control in the study. The sampling in the forest was done at only one point in time, this being at the end of the rainy season (210 days post-burn). However, at least as a coarse approximation, one can assume that the value from this sampling serves as a control for the whole series of samples in the pasture.

The experimental design followed that of another study carried out in the same area that had 36 subplots distributed in the form of rays emanating from two fixed points; half of the subplots were marked for pre-burn sampling and the other half for post-burn sampling (3).

Each individual soil sample was composed of three sub-samples distributed haphazardly within the subplot. In the pasture we collected a composite sample in each of the pre-burn subplots (n=18), and one in each of the post-burn subplots (n=18) at 7 days after the burn. Samples in the pasture were also taken at 120 and 210 days after the burn, each sample being composed of cores taken at 12 different points, chosen randomly but avoiding the initial subplots so that there would be no effect from the movement of people working in the plots during the studies conducted at the site. In the forest we also took 12 samples, 6 being from forest at each side of the pasture, assuming that the previous vegetation was continuous without physiognomic changes. To correct the values for carbon stocks obtained by chemical analyses, we determined soil bulk density using the volumetric cylinder method modified from (4). In this way, equal weights of soil for forest and pasture were considered in the analysis, with the result that the stock of carbon in the pasture is based on a depth slightly less than in the forest due to the change in density. The volumetric cylinder method was used so that only the effect of the fire would be measured, eliminating the effect of compaction following the calculations of (10).

Soil total organic carbon (% C) was determined by the dry method, which converts the forms of carbon present in the soil into carbon dioxide by combustion at 1100oC. The CO2 is then sent to an NaOH cell (standard), where the difference in electrical conductivity between this solution and a standard one carbonated with CO2 is detected and the result is converted to mg of carbon (8). Using the results of the chemical analysis we determined the mean concentration (%) and the standard deviation of the stock (t.ha^{-1}) of organic carbon in the soil, as well as its variation in the pool over different sampling periods.

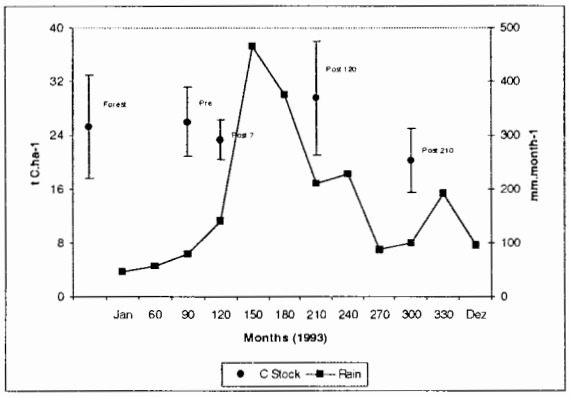
RESULTS

In absolute terms, organic carbon in the pasture soil prior to burning was reduced by 2.6 t C.ha^{-1} after the burn in the soil layer equivalent to the 0-20 cm horizon of forest soil (Table 1). However, this reduction was not statistically significant. The pre-burn value was regained after 120 days (during the rainy season), followed by a substantial decline by 210 days (beginning of the dry season) (Figure 1).

Table 1: Soil carbon stock and concentration at Colônia de Apiaú, Roraima

Vegetation type	Time with respect to burn	Season	Carbon concentration (%)	Carbon stock (tC.ha^{-1}) - mean(a)	- SD	Statistical difference(b)	Sample size(c)
Primary forest	-	-	1.15	25.3	7.62	1,2	12
Pasture (7-yr old)	0 days pre-burn	dry	1.18	26.0	5.18	1,2	18
	7 days post-burn	dry	1.07	23.4	2.94	1,3	18
	120 days post-burn	rainy	1.35	29.6	8.50	2	12
	210 days post-burn	intermediate	0.92	20.2	4.74	3	12

Figure 1. Oscillation of soil carbon stock (t C.ha-1) under pasture in relation to the seasonal cycle of rainfall in the Apiaú Colonization Area, Roraima, Brazil (Forest measured together Post 210).



The total carbon contained in the top 20 cm of soil under primary forest (25.3 t.ha^{-1}) was similar to the pre-burn total (26.0 t.ha^{-1}) and the post-burn total 7 days after burning (23.4 t.ha^{-1}), when compared by the Student-Newman-Keuls (SNK) test. However, primary forest, pre-burn and post-burn at 120 days (29.6 t.ha^{-1}) are significantly different from the result at 210 days post-burn (20.2 t.ha^{-1}) at $P<0.01_{(1),4,67}$. When compared separately, the 120-day post-burn value also differed at the P<0.01 level from the 7-day post-burn value.

DISCUSSION

The seasonal cycle of soil carbon stock levels complicates assessment of the effects of conversion of forest to pasture. A persistent problem in interpreting published results on soil carbon changes with burning is that authors rarely report the dates of the pre- and post-burn samples, making it impossible to tell if the increases or decreases reported are due to the burning or to the normal seasonal cycle of soil carbon stocks.

The content and composition of the soil organic matter can be influenced as a result of seasonal changes (1), resulting in different phases of accumulation and loss of carbon in the soil under the system. The peak soil carbon stock observed during the rainy season (Figure 1) appears to be closely linked

to the increase in microbial activity and to the greater volume of fine roots during this period in pastures. Measurements taken in an Oxisol near Manaus indicate that these two components almost double in weight during the rainy season, as compared to the dry season, in a young *Brachiaria humidicola* pasture, especially in the 0-5 cm layer (23). A similar result was found by (29) in fertile soils (Andisols and Inceptisols) in Costa Rica in *B. dictyneura* pasture. This causes a little-studied effect in the dynamics of below-ground carbon allocation (especially to roots) in systems that are converted from forest and that are exposed to periodic burning and to marked seasonal variations. The seasonal cycle in carbon stocks results from the seasonality of carbon inputs, which are only partially offset by a seasonal cycle in soil respiration that also peaks during the rainy season (19).

Our study indicated that, relative to the carbon stock in the rainy season (29.6 $t.ha^{-1}$), there was a significant decrease in total carbon in the soil at the beginning of the dry season (20.2 $t.ha^{-1}$). Water deficit and lower microbial activity could have contributed to this result due to unfavorable edaphic conditions affecting the decomposition of biomass remains in the 0-20 cm horizon of the soil. Conversion of forest to pasture reduces the water storage capacity of the soil (9), and confines the distribution of inputs of carbon from the roots to the surface layers (25). Both of these factors, together with high rates of decomposition (oxidation) of soil carbon, could result in a decline in the soil carbon stock (26).

Our results over the short term indicate that, in addition to burning, climatic conditions are intimately connected to the humification and degradation of organic matter in the soil and, therefore, to the stock and release of carbon. In other words, repeated burning, change from a high- to a low-biomass system, trampling by hooves of the cattle, and exposure to rain and direct sunlight can cause small local effects that, accumulated over the long term, could transform the landscape from productive pasture into a degraded system and a net source of carbon to the atmosphere.

CONCLUSIONS

Short-term changes in soil carbon stocks are heavily influenced by the seasonal cycle of rainfall, which increases soil carbon stocks during the rainy period. The seasonal cycle can mask the effect of burning and other consequences of land use change. Over longer periods, the data from the current study suggest a decrease in soil carbon stock. Some of the varied responses of soil carbon stocks to land-use conversion reported in the literature may be explained by the short-term changes investigated in the present study. The question remains open as to whether tropical soils undergoing periodic burning are net sources of carbon to the atmosphere.

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RESUMO

Queimada de pastagem na amazônia: mudanças no estoque de carbono no solo em curto prazo. Foi estudado o efeito da queimada no estoque e na liberação de curto prazo do carbono do solo em uma pastagem de 7 anos da Amazônia brasileira. As medidas foram realizadas na pastagem antes (pré-queima) e aos 7, 120 e 210 dias após a queimada (pós-queima) ao longo das estações chuvosa e seca. O carbono do solo da floresta primária adjacente (controle) também foi medido. O estoque de carbono aos 210 dias pós-queima (20,2 t C. ha^{-1}) foi significativamente menor do que os demais valores observados, com exceção do estoque de 7 dias pós-queima (23,4 t C. ha^{-1}) ($P<0.01_{(1),4,67}$, Teste SNK). O restante dos valores amostrados não diferiu significativamente entre si. Houve uma perda numérica de 2,6 t C. ha^{-1} no estoque de carbono presente nos 20cm iniciais do solo (equivalente ao da floresta) entre a pré-queima (26,0 t C. ha^{-1}) e a pós-queima de 7 dias que não foi estatísticamente significativa. Nenhum dos dois estoques diferiu significativamente do encontrado na floresta primária (25,3 t C. ha^{-1}). O estoque de carbono do solo aos 120 dias pós-queima (29,6 t C. ha^{-1}) também não diferiu da floresta primária e da pastagem pré-queima. A oscilação sazonal dos estoques de carbono no solo é aparente na pastagem e, até que a estação chuvosa se encerre, este efeito é capaz de mascarar o efeito da queimada. Os resultados sugerem que a perda de carbono pela queima e mineralização são maiores do que o ganho por humificação das raízes e remanescentes vegetais. Entretanto, o efeito acumulativo destes desequilíbrios somente se transformam evidentes após um determinado tempo transcorrido (neste caso 210 dias). Carbono do solo em pastagens amazônicas indica ser perdido em pequenas quantidades ao longo do tempo sob as atuais práticas de manejo.

Palavras chaves: carbono no solo, Amazonia, queimadas, fogo, pastagens, matéria orgânica.

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