Soil Carbon and Nitrogen Dynamics After Pasture Installation in the Amazon Region

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SOIL CARBON AND NITROGEN DYNAMICS AFTER PASTURE INSTALLATION IN THE AMAZON REGION

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Abstract

The objective of this paper is to present the soil carbon (C) and nitrogen (N) dynamics in a chronosequence made of a forest and pastures of different ages established in a Oxisol in the Western Brazilian Amazon Basin. The results of soil Carbon and Nitrogen stocks and gases fluxes were discussed. Stable ^{13}C isotopic technique was used to calculate for a determinate age of pasture installation, the proportion of soil C remaining from the forest system and the proportion of soil C introduced by the grasses of the pasture system. The C lost from the original pool under the forest is 1.0 to 1.6 kg C m^{-2} concentrated during the first 5 years as pasture, and that the C fixed by the pasture (net fixation) is 1.7 to 2.3 kg C m^{-2} for the total period of 35 years. We agree with the assumption that cattle ranching would never be a profit-making venture as long as only the revenue from the sale of cattle is taken into account. But, now a days, the notions of taxes or refunds for C sequestration and land rehabilitation turn the management of areas that have already been converted to pasture a strategy for C sequestration.

Keywords: Soil, carbon, nitrogen, dynamic, isotopes, pasture, Amazon

Introduction

The Amazon Basin covers an area of 7,050,000 km^2, and the central part is almost entirely located within the Brazilian territory. The Basin has a hot and humid climate, however, because of its size, this region presents a large diversity of local climates (Salati and Marques, 1984). Two main soil divisions of the Brazilian soil classification, Latossolos (Oxisols) and Podzólicos (Ultisols and Alfisols) cover nearly 75% of the total area (Rodrigues, 1996).

The region has the highest rates of deforestation in the world. Clearing rates varied between 15,000 and 29,000 km^2 yr^{-1} over the past two decades, and the total area deforested now exceeds 500,000 km^2 (INPE, 1998). Cattle pasture dominates the use of the once-forested land in most of the basin (Serrão, 1992, Skole et al., 1994). Fearnside and Barbosa (1998) estimated that 75% of the deforested land have been managed as pasture for some period of time. Despite the predominance of forest to pasture conversion, few information currently exists about soil organic matter (SOM) stocks and cycling pattern changes following pasture installation.

The objective of this paper is to present the soil carbon (C) and nitrogen (N) dynamics in a chronosequence made of a forest and pastures of different ages established in a Oxisol in the Western Brazilian Amazon Basin.

Material and Methods

Chronosequence description

The chronosequences at Nova Vida ranch (Rondônia, Figure 1) consist in native forests and pastures between 3 and 81 years old. They represent one of the best knows and longest sequences in the Amazon Basin. Pastures were also converted directly from forest without an intermediate use for annual crops cultivation. This makes them particularly valuable for evaluating the effects of continuous pasture use alone, without the confounding factor of other brief cropping phase that is common in the Amazon and which complicates many pastures studies. Sites in Nova Vida sequences were within 5 km of each other and in areas of similar topography (Neill et al., 1995; Moraes et al., 1996). Soils were classified as Podzólico Vermelho Amarelo (Red Yellow Podzolic) in the Brazilian classification scheme and as Ultisols (kandiuldults and paleudults) in the U.S. soil taxonomy (Moraes et al., 1995; Moraes et al., 1996) and had similar clay content and texture.

All pasture in the chronosequences were established in a similar manner by slashing, burning after the first rains in September and October, and planting pasture grasses (*Brachiaria brizantha* or *Panicum maximum*) in December or January. Selective logging in the forests removed about 3-4 trees per hectare. All pasture had similar management. They were actively grazed at an average annual rate of approximately one animal per hectare. No mechanized practices were used, and as it is usual, no fertilizers were used due to the high costs of chemical products that have to be transported from the Southern states of Brazil. Pasture were burned every 4-10 years to control weeds. Due to its very superficial action, burning is harmless to the soil structure, but it strongly modifies the distribution and activity of soil fauna and microbial communities. Data from an experimental farm in Eastern Amazon Basin published by Martins et al. (1991) showed that the chemical characteristics of surface soil were drastically modified as a consequence of plant cover burning. In this way, burning is frequently considered an advantageous source of fertilizers, as the sum of exchangeable bases generally increases and exchangeable aluminum decreases.

Transformations from aboveground biomass burning were already evaluated for a forest at Fazenda Nova Vida and published by Graça et al. (1999). Briefly, the above-ground biomass dry weight before the burn was estimated at 313.3 t dry matter ha^{-1}, and the corresponding C stock was estimated at 142.3 t C ha^{-1}. After the burn this stock was reduced by 34.6% (burning efficiency). This implies a transfer of 49.2 t C ha^{-1} to the atmosphere. The quantity of C in the charcoal and ashes formed in the burn corresponded to only 3% of the total above-ground C stock present before the burn. Graça et al. (1999) concluded that the distribution of initial biomass among the classes of plant material explained most of the differences among values for burning efficiencies found in Amazonia.

Sampling and analysis

Soil samples, excluding the litter layer, were obtained at each site from five pits to a depth of 50 cm. Samples were further prepared by air drying and sieving (2 mm) to remove stones and root fragments. Soil bulk density, texture, pH, effective cation exchange capacity (ECEC), and C and N concentrations were measured by using techniques described in Anderson and Ingram, 1989; EMBRAPA, 1979; and Moraes et al., 1996. For example, particle size fractions were determined by hydrometer after dispersion in a mixer with hexametaphosphate and digestion of organic matter with H_2O_2. Soil pH was measured in water (2.5:1) on air-dried soil. Potassium, calcium, and magnesium were extracted with ammonium acetate at pH 7 and analyzed by emission spectrophotometry. Aluminum was extracted with unbuffered KCl and analyzed by emission spectrophotometry. Total C and N were analyzed by combustion on a Perkin-Elmer 2400 Elemental Analyzer. Bulk density was measured in the field with volumetric steel rings. Soil samples were analyzed for $\delta\ ^{13}C$ on a Micromass 602E or a Finnigan Delta-S mass spectrometer.

When forest is cut and converted to pasture, ^{13}C isotope techniques can be used to estimate SOM turnover and different types of C pools, from very labile/active to very resistant/passive (See Bernoux et al., 1998 for the theory).The ratio of $^{13}C/^{12}C$ of the sample was expressed in δ values in parts per mil relative to the PDB standard. Soil organic C fractions were separated physically by floating, sieving, and centrifugation (Feigl et al., 1995). Respiration rates were determined from field measurements using incubation chambers (Neill et al., 1997). Some analyses were not performed on every site from both chronosequences.

Stocks of C were calculated and corrected based on sampling of a total soil mass in the pastures that was equal to the same soil mass in the original forest.

Results and Discussion

Soil C and N stocks

Land-use practices affect soil C stocks by modifying inputs to soil as well as the decomposition rate of SOM. Recently, Shang and Tiessen (1997) pointed out that organic matter in tropical Oxisols is quite labile. They showed that a rapid degradation of this pool is possible under cultivation and therefore organic matter monitoring and management should be a priority. Fearnside and Barbosa (1998) reviewed the soil C changes from conversion of the Brazilian Amazon forest into pasture. These authors pointed out that pasture soils are a net sink or a net source of C depending on their management, and that most pasture are under management practices resulting in a net C source.

Moraes et al. (1995) showed that total soil C increases 9% after 5 years and 19% after 35 years of pasture installation when compared with the same soil under forest. C content (0-30 cm) was 3.5 kg C m^{-2} and 3.3 kg C m^{-2} respectively in both forest sites from the chronosequences. Evolution patterns were similar for both chronosequences. Using data from Nova Vida (Table 1) and from other Amazonian chronosequences, an average value of 4.0 kg C m^{-2} that is stored in pasture soils could be determined. This value correspond to an increase of 0.36 and 0.76 kg C m^{-2} respectively. Using stable ^{13}C isotopic technique (Cerri et al., 1985; Bernoux et al. 1998) it is possible to calculate for a determinate age of pasture installation, the proportion of soil C remaining from the forest system (Cf) and the proportion of soil C introduced by the grasses of the pasture system (Cp). We calculated that, after 5 years as pasture, the proportion of Cf varied from 55.7 to 68.7% and Cp from 31.3 to 44.3%. For the period of 35 years the proportions were 51.3-64.8% for Cf and 35.2-48.7% for Cp. It is therefore possible to show that the C lost from the original pool under the forest is 1.0 to 1.6 kg C m^{-2} concentrated during the first 5 years as pasture, and that the C fixed by the pasture (net fixation) is 1.7 to 2.3 kg C m^{-2} for the total period of 35 years.

Nitrogen contents did not presented the same pattern of increasing along both chronosequences as observed for C. Both forest sites presented basic the same N content (0.33 kg N m^{-2}). After pasture establishment the stocks of this element ranged between 2.99 kg N m^{-2} to 3.80 kg N m^{-2} in the first chronosequence and between 2.74 kg N m^{-2} to 4.50 kg

N m^{-2} in the second chronosequence. Except for the eight year old pasture of the second chronosequence, the mass C:N ratio were higher in the surface soils of other pastures compared with the regional forest. The C:N ratios were generally in the range of 8 to 16. The higher C:N ratios in the pastures is consistent with the relatively greater accumulation of C relative to N in the older pastures.

Carbon and Nitrogen fluxes

Conversion of tropical forests to pastures occurs on a large scale and is believed to substantially alter the global budgets of several greenhouse gases. To assess the effect of forest conversion on trace gas fluxes, we measured the soil-atmosphere exchanges of CO_2, CH_4 and N_2O for one year in open moist tropical forests and along pasture chronosequences. Gas exchange rates showed large differences between the forests and pastures and large seasonal variations.

According to Feigl et al. (1995), pasture soils generally had greater CO_2 emissions throughout the year than the forest soils. The largest releases (up to 310 mg CO_2-C m^{-2} hr^{-1}) were measured during the wet season in the 5 and 9 year-old pastures. The $\delta^{13}C$-CO_2 values from field incubations showed that the C in the respired CO_2 was primarily pasture-derived C (C-4) in pastures older than 5 years.

Forest soils always consumed atmospheric CH_4. Uptake rates were greatest during the dry season (0.063 mg C m^{-2} hr^{-1}) and were 2 times lower during the wet season. Pasture soils consumed CH_4 during the dry season but uptake rates were generally less than in the forests. Pasture soils were a CH_4 source (up to 1.36 mg C m^{-2} hr^{-1}) during the remainder of the year. On an annual basis, pastures were a net source of CH_4 to the atmosphere (Steudler et al., 1996) This finding has important implications for understanding the role of tropical ecosystems in the global atmospheric CH_4 budget.

Dry season forest soil N_2O emissions averaged 13.7 μg N_2O-N m^{-2} hr^{-1} and increased about 2.5 times during the wet season. Pastures had N_2O emission rates comparable to the forest during the dry season. During the wet season, N_2O fluxes from the younger pastures (3-,5- and 9- years) were greater than from older pastures (14-, 20-, 41- and 81 years), but the N_2O pasture emission rates are lower than those reported for other tropical pastures. This may be due to differences in the factors controlling N_2O emissions such as soil moisture, pH and C and N dynamics.

Conclusion

It is commonly considered that cattle ranching would never be a profit-making venture as long as only the revenue from the sale of cattle is taken into account. But, now a days, the notions of taxes or refunds for C sequestration and land rehabilitation turn the management of areas that have already been converted to pasture a strategy for C sequestration. Nevertheless, the problem of the pasture management remains crucial, and unfortunately no estimate of the extent that pasture well managed exists with the same regime as the pasture studied and taken as central reference.

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Table 1 - Values of total C for 0-30 cm layer of one chronosequence, and its segregation into the pools Cf and Cp calculated using $\delta^{13}C$ values (data adapted from Bernoux et al., 1998).

Pasture age (years)	Total C	Cf	Cp
	kg C m^{-2}		
Forest (Reference)	3.53	3.53	-
2	4.03	3.46	0.57
4	4.55	3.43	1.11
8	4.19	2.75	1.44
14	3.73	2.05	1.68
20	4.33	2.10	2.23

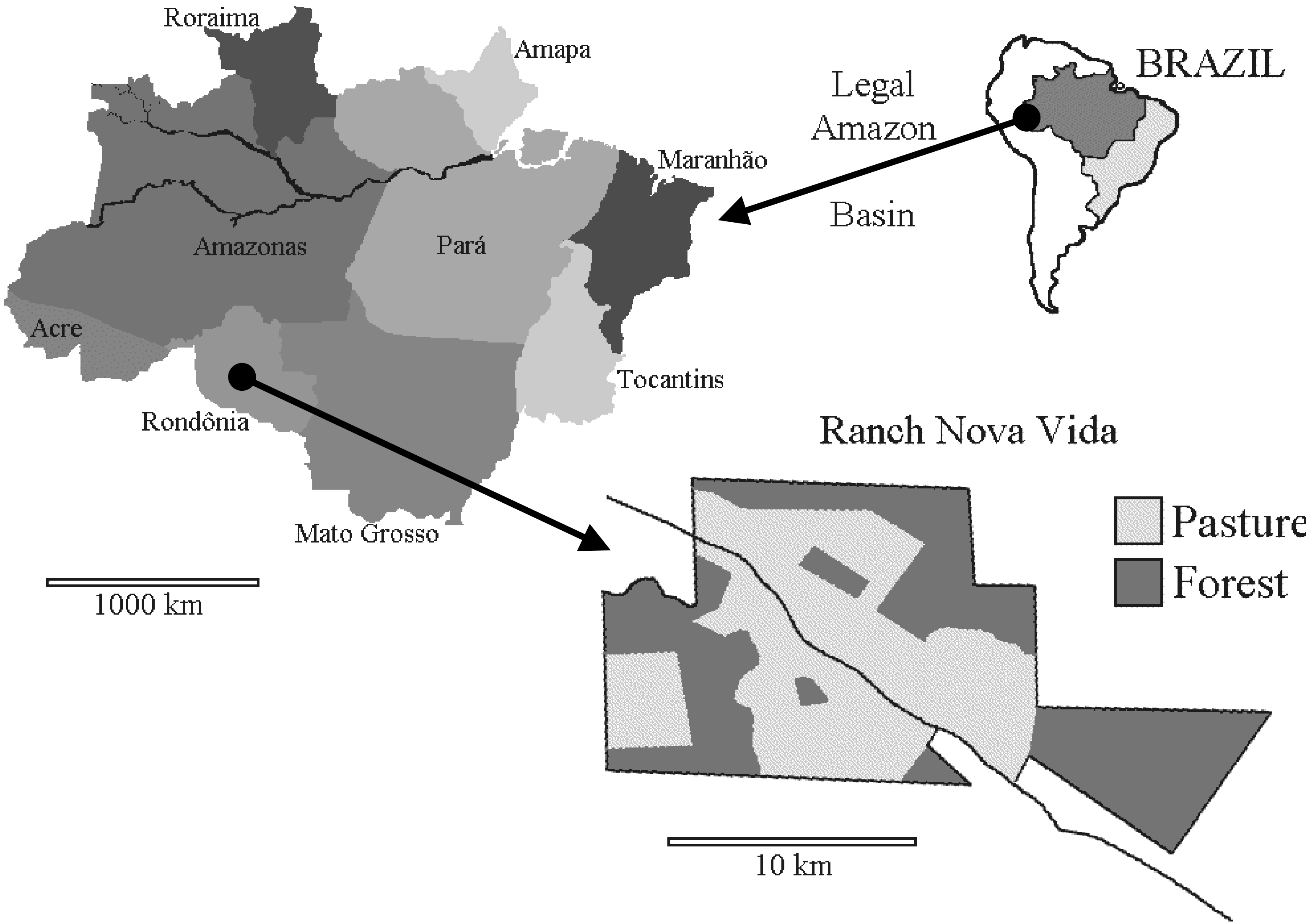

Figure 1 - Brazilian Amazon states and localization of the Ranch Nova Vida