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Changes in soil carbon stocks after land-use change from native vegetation to pastures in the Atlantic forest region of Brazil

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ABSTRACT

Millions of hectares (ha) of the Atlantic forest of Brazil have been deforested and replaced by pastures, quite a large proportion of this in the last 60 years. There have been few studies on the impact of this land-use change on stocks of soil organic matter (SOM) only one study reported the state of vigour of the pastures. The aim of this study was to estimate the overall change in SOM stocks 16 years after the removal of forest vegetation in this biome in southern Bahia and the installation of pastures of *Brachiaria brizantha* fertilized with N and maintained under controlled grazing. Soil samples were taken for evaluation of density and texture and for analyses of C and N total and ^{13}C abundance to a depth of 100 cm at 100 m intervals along four transects of 400 m from the pastures into the forest. Grazing was found not to have any significant effect on soil density (compaction). The live weight gain of the Nellore cattle on both cultivars of *B. brizantha*, fertilized with 120 kg N ha^{-1} yr^{-1} as urea during 12 years, was close to 500 kg ha^{-1} yr^{-1}. The gain in soil C was similar under the two grass cultivars, being approximately 15 Mg C ha^{-1} to a depth of 30 cm and 20 Mg C ha^{-1} to 100 cm. The ^{13}C abundance data showed that the large gain in soil C was due to the slow decomposition of the forest-derived C (total loss 12.6 Mg C ha^{-1} over 16 years) and the large accumulation of C derived from the *Brachiaria* (total gain 43.2 Mg C ha^{-1}). These results confirm the potential of productive *Brachiaria* pastures to accumulate soil C in a tropical climate with year-round rainfall.

1. Introduction

A recent estimate of the global impact of land use and land use change suggests that there has been a transfer of 133 million tons (Tg) of C from soils to the atmosphere due to historical anthropogenic activity, Brazil being within the 10 largest soil CO_2 emitters in the world (Sanderman et al., 2017).

Brazil's large contribution of CO_2 emissions due to land use change is relatively recent and motivated principally by deforestation to secure tenure of land, using pasture as the cheapest manner to “use” the land for an economic benefit. This process initially drastically affected the Atlantic Forest biome that covers 130 million hectares (Mha) (Boddey et al., 2003; Desacato, 2017). From 1994 to 2002, 1.8 million ha of the remaining area of managed and non-managed forest (< 10% of the original area) gave space to pastures, a figure that increased to 2.8 million ha from 2002 to 2010. In 2010, the pasture area in the biome was 40 million ha (MCTI, 2015).

There are a few studies that have investigated how pastures affect soil C stocks in the Atlantic Forest biome (Tarré et al., 2001; Vicente et al., 2016), but they reinforce the general idea that this land use change has positive impacts on soil C stocks when pastures are well managed.

The quantity of soil organic C stored in the soil depends on the rate of deposition of plant residues and their rate of decay. In the case of natural vegetation or pastures, the soil remains largely undisturbed physically. One consequence is that pasture or crop residues derived from the aerial tissue are not integrated into the bulk of the soil unless by action of soil fauna or by leaching of suspended particles or soluble carbon. It is therefore evident that most soil organic matter (SOM) is derived from root residues. The absence of soil disturbance/tillage also preserves macro-aggregates which foster the formation of micro-aggregates (Six et al., 2000; Denef et al., 2007; Barreto et al., 2009),

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where SOM can be occluded or form mineral-organic complexes protecting it from microbial decomposition (Dungait et al., 2012).

When there is a change in land use, the quantity and distribution of organic matter in the soil profile will also change. The SOM derived from the original land use will gradually decompose and be replaced at a higher or lower rate by the SOM derived from the new land use. In most situations, the rates of decomposition (C loss) of the "old" C and the accumulation of "new" C cannot easily be assessed, but this is possible when there is a land-use change from tropical forest (predominantly vegetation of the Calvin C_3 photosynthetic pathway) to tropical grasses of the C_4 photosynthetic pathway (Cerri et al., 1985). These two pathways of C fixation by C_3 and C_4 plants are easily distinguishable from the ^{13}C abundance of the plant tissue (Farquhar et al., 1989). In general, C_3 plants present a ^{13}C abundance between −25 and −28 ‰ and C_4 plants between −10 and −14‰. The isotopic abundance of carbon (^{13}C) of plants possessing these different photosynthetic pathways is sufficiently different to be detected with ease by modern isotope-ratio mass spectrometers and the ^{13}C signal is largely conserved during the processes of decomposition and humification of SOM (Cerri et al., 1985; Wedin et al., 1995). Consequently, the determination of the ^{13}C abundance of soil provides a sensitive technique to examine the progress of the decomposition of forest-derived soil organic C and the contribution of C derived from the new source of soil C, that of the C_4 tropical grass.

Cerri et al. (1985) adopted a simple mixing model to calculate the proportions of C in soil organic matter derived from C_3 and C_4 plants. The equation developed expresses C_F, the fraction of C derived from C_3 plants as:

$$C_F = (\delta^{13}C_{CS} - \delta^{13}C_{C4})/(\delta^{13}C_{C3} - \delta^{13}C_4)$$

where $\delta^{13}C_{CS}$, is the ^{13}C abundance (measured in $‰_{PDB}$) of the sample taken from an area which has both C_3 and C_4 plants. This often an area which was in primary (C_3) forest and has now been replaced with tropical grasses such as *Brachiaria*, sugarcane or maize. $\delta^{13}C_{C4}$ and $\delta^{13}C_{C3}$ are respectively the ^{13}C abundances of soil derived solely from C_3 and C_4 plants.

Several studies have been published in Brazil using this technique where native forest in the Amazon was replaced by forage grasses of the genus *Brachiaria* (e.g. Trumbore et al., 1995; de Moraes et al., 1996; Neill et al., 1997). For the areas of *Brachiaria* pastures, the data show the replacement of the previously existing SOM derived from the C_3 vegetation by the new input of C_4-C. In some cases, the quantity of newly deposited C_4-C was greater than the loss of the original C_3-C and a net gain in soil C was reported (de Moraes et al., 1996; Koutika et al., 1997). However, in none of these studies was there any measure of the productivity of the pastures, and in some cases the number of years since the land-use change occurred was not known.

The objective of this study was to examine how soil C and N stocks changed after 16 years of land-use change from Atlantic Forest vegetation to pastures of contrasting cultivars of *Brachiaria brizantha*, where the history and productivity of the pastures had been continuously monitored.

2. Material and methods

2.1. Site and history

The study was conducted at the Animal Husbandry Station (ESSUL-CEPLAC – 16°39′S, 39°30′W) of the Cocoa Research Organization (CEPLAC/CEPEC) near Itabela in the extreme south of Bahia State in the Atlantic forest biome. The experiment was originally established in January 2000 as a part of a multi-site trial to study the long-term performance of cattle grazing two new cultivars (Arapoti e Xaraés) of *Brachiaria brizantha* in comparison with the common cultivar Marandú. The cultivar Marandú of *B. brizantha* is that which dominates the area planted to *Brachiaria* in Brazil and was originally released in 1984. The cultivar Xaraés is a leafy, highly productive cultivar with late reproductive stage, different from Arapoti of early reproductive stage (Rodrigues, 2004), but Arapoti shows greater tolerance to flooding (Caetano and Dias Filho, 2008).

Mean annual rainfall for Itabela is 1300 mm with no marked dry season. During the 16 years of the study rainfall averaged 127 mm mo^{-1} in the summer months (October to March) and 95 mm mo^{-1} in winter (April to September). Mean maximum and minimum temperatures were 29.4 °C and 21.2 °C, respectively, in summer and 21.2 °C and 18.9 °C in winter. The soils in this region belong to the Coastal Tablelands ("Tabuleiros Costeiros"). The soil at the site of the study is classified by the Brazilian system as "Argissolo Amarelo Distrófico coeso" or by the FAO Classification a Haplic Acrisol (Abruptic, Hyperdytric). A total of five soil samples were taken in the area before removing the native vegetation to depth of 20 cm and analyzed for chemical characteristics using the standard methods recommended by Embrapa (Claessen et al., 1997) in the laboratories of Embrapa Agrobiologia. The soil showed the following characteristics: pH 5.3, exchangeable cations (cmol kg^{-1}) Ca, 2.5; Mg, 0.5; K, 0.07; Al 0.0; available P (Mehlich 1), 1.0 mg kg^{-1}; total C (Walkley Black), 1.23 g kg^{-1}.

The area of the study was flat and uniform and, until 1998, covered by native forest vegetation. In that year an area of 12 ha of the forest (600 × 100 m) was cleared of vegetation and in the following year ploughed and harrowed to incorporate 1.2 Mg ha^{-1} of dolomitic lime. In 2015 at the time of soil sampling for soil C and N the mean (16 replicates) pH was found to be 5.8 in the 0–10 cm depth interval. In 2000 the area was fertilized with 35 kg P ha^{-1} as single superphosphate and 40 kg N ha^{-1} as urea, divided into 12 paddocks of 1 ha each and all were planted to different cultivars of *Brachiaria* spp.. At the eastern end of the cleared area, two paddocks were planted to the cultivar Xaraés of *B. brizantha* and adjacent to these paddocks on the western side, the Arapoti cultivar of the same species (Fig. 1). In both cases seeds were supplied by the Embrapa Beef Cattle Centre in Campo Grande, Mato Grosso do Sul. For all paddocks, a further 40 kg N as urea was added at 120 and 240 days after planting (DAP) and this fertilization (40 kg N ha^{-1}) continued for 3 times a year until 2012. From 2005 to 2010, phosphorus 17.5 kg P ha^{-1}, as single superphosphate, and 52 kg K ha^{-1} as potassium chloride, were added annually.

2.2. Soil sampling

In May of 2015 soil samples were taken from two parallel transects in an east-west direction reaching across the two paddocks of cv. Arapoti into the forest and in the same manner for the cv. Xaraés paddocks as shown in Fig. 1. Pits (1 × 1 m area) were dug to a depth of 120 cm at each sampling point spaced 100 m from each other along the transect (at four points in the area of each *B. brizantha* cultivar and four points due west along the transects in the neighboring the forest – Fig.1). Samples were taken with beveled rings (4.98 cm diameter × 4.5 cm in length) from the four walls of the trenches in the center of each depth interval (0–5, 5–10, 10–20, 20–30, 30–40, 40–60, 60–80 e 80–100 cm) as described by Sisti et al. (2004). These samples were bulked for each depth layer from each trench and dried at 110 °C for the calculation of soil bulk density.

Four samples were taken from each entire depth interval in each trench, bulked as before, disaggregated and passed through a 2 mm sieve and air dried. Sub-samples were taken for standard soil fertility parameters (pH, exchangeable Ca, Mg, Na, Al and Mehlich I available P and K) and also for sand, silt and clay content on dispersed soil. All procedures were according to Claessen et al. (1997). Other sub-samples were taken for fine grinding using a roller mill (Arnold and Schepers, 2004) and subsequently analyzed for total N and C and ^{13}C-isotopic abundance using a continuous-flow isotope-ratio mass spectrometer (Finnigan DeltaPlus or Delta V mass spectrometer coupled to the output of a Costech [model ECS4010] total C and N analyser – Finnigan MAT,