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Soil organic matter dynamics and land-use change on Oxisols in the Cerrado, Brazil

Maria-Regina Gmach [a], Bruno O. Dias [b], Carlos A. Silva [c], Júlio C.A. Nóbrega [d], José F. Lustosa-Filho [c], Marcos Siqueira-Neto [e,f,*]

[a] College of Agriculture "Luiz de Queiroz", University of São Paulo, Piracicaba, SP, Brazil
[b] Department of Soil and Rural Engineering, Federal University of Paraíba, PB, Brazil
[c] Department of Soil Science, Federal University of Lavras, MG, Brazil
[d] Center for Agrarian, Environmental and Biological Sciences, Federal University of Recôncavo da Bahia, BA, Brazil
[e] Center for Nuclear Energy in Agriculture, University of São Paulo, Piracicaba, SP, Brazil
[f] Center of Agrarian and Environmental Sciences, Federal University of Maranhão, MA, Brazil

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ABSTRACT

Land-use change (LUC) from native vegetation to feedstock production is the main responsible for the losses of carbon (C) from soil organic matter (SOM) to atmosphere. We evaluated different land-uses common in the Cerrado with potential to restore SOM levels. We sampled soil (0.0–0.1; 0.1–0.2; 0.2–0.3; 0.3–0.4 m) from sites located in the municipality of Uruçuí (Piauí State, Northeast region of Brazil). Land-uses evaluated were: i) native vegetation (NV); ii) no-tillage over six years (NT_6); iii) no-tillage over nine years (NT_9); iv) *Urochloa brizantha* pasture over two years (PA_2); v) *U. brizantha* pasture over six years (PA_6); vi) *Eucalyptus urophylla* afforestation over six years (EU_6); and vii) *E. urophylla* afforestation over twelve years (EU_{12}). We determined soil C stocks, chemical (fulvic and humic acids) and physical (particulate and organic-mineral complexes) SOM fractions. Pasture was land-use that presented better results in terms to maintain C pools (recalcitrant and labile), consequently could restore soil C stocks. The no-tillage, due to the high difference between the results for the adoption times, was difficult to have an accurate interpretation if is effectively increasing the C stocks. On the other hand, Eucalyptus afforestation does not seem to be an efficient land-use when it comes to the restoration of SOM levels, at least under the current management practices as well as the soil and climatic conditions in the Cerrado.

1. Introduction

The Cerrado biome is a complex of plant formations that occupies approximately 2 million km^2 in the Brazilian territory (Brazil, 2018). It occurs in several regions of the country; its phytophysiognomy is highly diverse, depending on edaphic-climatic conditions (Ribeiro and Walter, 1998). The Cerrado in Piauí State is part of a region called MATOPIBA (because occupies part of the Maranhão, Tocantins, Piauí and Bahia States) and occupies about 11% (8.2 Mha) of the state territory (Embrapa, 2014) and accounts for a considerable percentage of the Brazilian grain (2% - rice, maize and soybean), fiber (1% - cotton) and livestock (1% - beef cattle) production (IBGE, 2018). Because of soil and climate characteristics favorable to the development of agricultural produce with high economic values, attracts new investors, has placed this region in the focus of potential ecosystem changes to expansion of feedstocks production areas.

Land use change (LUC) is the transformation of large parts of a landscape, directly altering its capacity to maintain its ecosystem services (Foley et al., 2005). Such changes are generally associated with the production of feedstock (food, fiber, bioenergy). Nevertheless, within the current LUC standards, the conversion of natural vegetation into agricultural areas is still the main factor of deforestation, especially in the tropics (Karp et al., 2015). Within a relatively short-time, LUC may significantly change the physical and biogeochemical properties of Cerrado soils (Hunke et al., 2015), through a reduction in organic material inputs to the soil (Lal, 2004; Saidy et al., 2013), consequently, reducing soil organic matter (SOM) (Ashagrie et al., 2007; Don et al., 2011; Corbeels et al., 2016; Matias et al., 2009; Siqueira-Neto et al., 2010).

SOM is the largest C stock in the biosphere (Lal, 2004) and formed by a complex and heterogeneous mixture of organic composts in different degrees of biochemical transformation, which more stable forms are generally associated with mineral soil fraction (Zinn et al., 2005). To maintain soil C stocks, the SOM needs to be in chemically more stable fractions (recalcitrant-C pools), such as humic substances (HS), which are formed by resynthesis processes and are relatively inert in the soils (Silva and Mendonça, 2007) and with longer response time to

* Corresponding author at: Center for Nuclear Energy in Agriculture (CENA/USP), Av. Centenário, 303, P.O. Box 96, 13400-970, Piracicaba, SP, Brazil.
E-mail address: msiqueir@usp.br (M. Siqueira-Neto).

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land-use and management changes (Rumpel and Kögel-knabner, 2011). On the other hand, a minor amount of SOM it's formed by less complexed C compounds (labile-C pools), which are characterized by their rapid turnover and are therefore more sensitive to management changes or variations in environmental conditions than total C stocks (Duxbury et al., 1989). In this sense, the particulate organic matter (POM) fraction plays an important role in soil nutrient availability, even as energy source for microorganisms; and it is influenced by residue quality, C:N ratio, climate, land-use and management (Bayer et al., 2004).

Agricultural systems in the Piauí Cerrado are characterized by intensive and frequent soil revolving (Pragana et al., 2012). In this context, the high rate of agricultural expansion, in which large areas are subjected to intensive mechanization, has raised concern about the potential impacts of LUC on ecosystem services provided by soils, mainly in terms of regulation and support (e.g. soil C stocks in SOM, retention and conservation of water resources, sources and cycling of nutrients) (Fu et al., 2015).

Several researchers have shown that LUC causes considerable SOM losses (Corbeels et al., 2016; Coser et al., 2018; Marchão et al., 2009; Salton et al., 2014; Sant-Anna et al., 2017; Siqueira-Neto et al., 2010; Zotarelli et al., 2012). Thus, it is assumed that in the MATOPIBA, where, predominantly, climatic conditions (high temperature and short-time rain season), soil characteristics (high sand content, clay fraction formed by low activity materials - Fe and Al oxide, low structuration with presence of cohesive horizon), besides soil revolving facilitates the organic material decomposition and SOM mineralization. This study tested the hypothesis that after SOM decline due to LUC, conservationist land-uses (e.g. no-till, well-managed pasture and *Eucalyptus* afforestation) can recover SOM levels through the organic material inputs (crop/grasses - above and belowground - residues) and sustainable management practices. Thus, we conducted a field study to evaluated different land-uses, common in this region of the Cerrado and recognized for their potential to increase SOM, to quantify their effects on soil C stocks, as well as SOM chemical and physical fractions.

2. Material and methods

2.1. Study site and treatment

The study was conducted in the municipality of Uruçuí (Piauí State, Northeast region of Brazil). The climate of the region is humid tropical of savannah type (Aw - Köppen's classification) with a high average annual temperature of 25 °C and a distinct rainy season from November to April; average annual rainfall ranges from 800 to 1200 mm (Aguiar and Gomes, 2004). The hydrological conditions favor a sub-deciduous character, drastically reducing the size and density of native vegetation (Jacomine et al., 1986). The phyto-physiognomy is classified as Cerrado *stricto* sensu to typical tropical savanna, which is characterized by the presence of low to medium sized water stress-resistant trees (Ribeiro and Walter, 1998). The soil was classified as a Yellow Oxisol (Jacomine et al., 1986) - Xanthic Ferralsols Dystric to Alic (IUSS Working Group WRB, 2014), deep, well-drained, with a low natural fertility and a sandy loam texture (Table 1).

The sampled treatments (land-uses) were: i) native vegetation (NV) with the phytophysiognomic characterized as dry shrubs savanna, with trees higher (1.5 to 3.0 m), this area was considered the reference because all land-uses were derived from similar situation; ii) a 6 yr old cropland under no-tillage (NT_6), with maize (*Zea mays* L.) and millet (*Pennisetum americanum* L.) as soil cover; iii) a 9 yr old cropland under no-tillage (NT_9), with soybean (*Glycine max* L.) and millet as soil cover; iv) a 2 yr old pasture planted with *Urochloa brizantha* Hochst. Ex A. Rich., continuously grazed by beef cattle (1 a.u./ha); v) a 6 yr old pasture planted with *U. brizantha* (PA_6), continuously grazed by beef cattle (1 a.u./ha); vi) a 6 yr old afforestation with *Eucalyptus urophylla* S. T. Blake (EU_6) and vii) a 12 yr old afforestation with *E. urophylla* (EU_{12}). Table 1 provides an overview over the different land-uses.

It is important to highlight that after LUC (LUC 1; Table 1), all land-uses were cultivated with rice in first year, using conventional tillage, due to rice plants can tolerate low pH values and low nutrient levels, whose yield reduce conversion costs. Subsequently, PA and NT areas (actually – LUC 2) were cultivated with soybean followed by winter (dry season) fallow, too using conventional tillage.

2.2. Soil sampling and analysis

The soil C content, chemical and physical fractionations of SOM were determinates in soil samples with four replicate collected in August 2013 (dry season). Prior to sampling, we established one-hectare plot in each treatments. Using a GPS device and a measuring tape, we marked 25 points at a distance of 25 m. Then four of these points were randomly selected to constitute the four replicates. At each point, an auger was used to collect eight sub-soil samples (i.e. 4 replicates composed of eight sub-samples) from layers depths 0.0–0.1, 0.1–0.2, 0.2–0.3 and 0.3–0.4 m. In laboratory, soil samples were air dried, homogenized and sieved at 2 mm to remove plant/crop and roots residues. To soil bulk density (BD) was collected one soil sample for each replicate using a steel cylinder in each layer. In laboratory, total soil was oven-dried at 105 °C and weighed for BD calculation (Blake and Hartge, 1986).

Soil carbon content was determined by dry combustion. The dry soil samples were sieved through a 250-μm (60 mesh) sieve and analyzed in a Vario TOC Elementar (Langenselbold, German). Soil carbon stock was calculated using the following equation:

$$(E = BD \times C \times e) \quad 1$$

where BD = bulk density (g cm^{-3}), C = carbon content (g 100 g^{-1}), and e = layer (cm).

Table 1
History of land-use and select soil physical-chemical characteristics (0.0–0.2 m) of the Xanthic Ferralsols with sandy loam texture in the Cerrado biome, Piauí State, Brazil.

Areas	LUC_1	LUC_2	Actual cultures	Sand	Silt	Clay	pH	Avail-P	CEC	Bs
	year			g kg^{-1}			water	mg dm^{-3}	$cmol_c$ dm^{-3}	%
NV	–	–	–	700	60	240	4.7	0.6	8.6	2.6
NT_6	2002/03	2007/08	Maize/Millet	770	30	200	4.8	30.3	7.8	31.9
NT_9	2001/02	2004/05	Soybean/Millet	810	50	140	5.0	31.6	7.5	35.8
PA_2	2001/02	2011/12	*U. brizantha*	760	50	190	4.8	17.0	7.6	31.9
PA_6	2000/01	2007/08	*U. brizantha*	760	70	170	4.9	8.0	7.9	26.1
EU_6	2006/07	2007/08	*E. urophilla*	800	10	190	5.2	2.2	6.8	33.5
EU_{12}	2000/01	2001/02	*E. urophilla*	800	30	170	5.1	5.2	6.4	32.8

NV: native vegetation; NT: no-tillage: PA: Pasture; EU: eucalyptus.
LUC_1: first land-use change – from native vegetation to convention tillage.
LUC_2: second land-use change – from conventional tillage to actual land-use.
Avail-P: available phosphorus; CEC: cations exchanges capacity; Bs: base saturation.