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Soil carbon changes in areas undergoing expansion of sugarcane into pastures in south-central Brazil

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ABSTRACT

In Brazil, sugarcane expansion for ethanol production has been predominantly on areas previously used as pasture. Losses of C and N induced by land use change raise controversies about the environmental suitability of biofuel production. Therefore, we conducted a field study within the largest sugarcane-producing region of Brazil to evaluate the effects of the primary land use change (LUC) sequence in sugarcane expansion areas (i.e., native vegetation to pasture to sugarcane), on C and N dynamics in the top 1 m soil layer. The LUC sequences caused substantial but varying changes in soil C and N stocks in areas undergoing expansion of sugarcane in south-central Brazil. The increase of C stocks in areas converted from pasture to sugarcane cultivation was 1.97 Mg ha^{-1} yr^{-1}, in contrast to conversion of native vegetation to pasture, which decreased soil C stocks by 1.01 Mg ha^{-1} yr^{-1} for 0–1.0 m soil layer. The use of ^{13}C measurements to partition soil C sources showed that the greater C stocks in sugarcane areas compared to pasture was due to retention of the native-C stocks and increased accrual of modern-C comparing to pasture. Finally, the inclusion of deeper soil layers, at least down to 1.0 m depth, is essential to assess the impacts of LUC on C balances in agricultural areas.

1. Introduction

The ethanol derived from 1 ha of sugarcane avoids the emission of about 14 Mg CO_2 eq yr^{-1} relative to the use of fossil fuels (Betts, 2011). When compared to other "first-generation" ethanol feedstocks such as corn, sugarcane is the most effective in mitigating greenhouse gases (GHG) emissions (Renouf et al., 2008). As a result, the global demand for sugarcane ethanol is rising (Goldemberg et al., 2014).

In Brazil, the largest producer of sugarcane ethanol in the world, the area cropped to sugarcane is expanding and the most pervasive scenario of land use change (LUC) is the conversion of pastures into sugarcane fields (Goldemberg et al., 2014; Lapola et al., 2014). Replacing pastures with sugarcane fields has been deemed an agronomically-feasible strategy for sugarcane expansion in Brazil. According to the Brazilian sugarcane Agroecological Zoning (Manzatto et al., 2009), there are 64 Mha suitable for sugarcane production, of which 34 Mha correspond to abandoned areas or degraded pastures (Walter et al., 2014). In addition, current government policies to enhance livestock productivity (BRASIL, 2012) could release grazed pasture area to sugarcane production without reducing food production or pressuring natural ecosystems (Goldemberg et al., 2014).

Land use change induces modifications of soil organic matter (SOM), which is one of the main source of uncertainty in life cycle assessments of biofuels (Qin et al., 2016). The C stored in the soil, which globally is more than three times the amount of C in the

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atmosphere (Batjes, 1996), plays a key role in GHG dynamics (Cotrufo et al., 2011). Several studies have demonstrated that the conversion from natural ecosystems to croplands or pastures decreases soil C stocks (Don et al., 2011; Eclesia et al., 2012; Assad et al., 2013), raising controversies about the environmental suitability of biofuels crops (Lapola et al., 2010). On the other hand, some studies have reported no net loss or even increases in soil C stocks with the replacement of natural vegetation to pastures in Brazil (Maia et al., 2009; Braz et al., 2013).

Isotopic techniques have been applied in studies of C dynamics, where forests with C3 photosynthetic pathway plants are replaced by C4 plants such as tropical forages and sugarcane (Assad et al., 2013; Rossi et al., 2013; Franco et al., 2015), to determine the soil C origin using $\delta^{13}C$ values. The determination of original C losses from natural vegetation and its replacement by the C derived from pasture or sugarcane is critical to understand the complex dynamics of C in soils following LUC. Although interpretation of $\delta^{15}N$ as a measure of impacts of LUC on N cycling and SOM dynamics in tropical agroecosystems is much more complex, some general inferences can be made (Lerch et al., 2011).

In a recent study, the conversion of pasture to sugarcane was found to produce a net C emission of 1.3 Mg ha^{-1} yr^{-1} over 20 years (considering the 0-0.3 m soil layer), primarily due to the loss of SOM from C4-cycle plants (Franco et al., 2015). However, the influence of LUC for sugarcane expansion on SOM dynamics and C-origin in deeper soil layers remains unclear.

Therefore, we conducted a field study within the largest sugarcane-producing region of Brazil to evaluate the effects of the most common LUC sequence in sugarcane expansion areas (i.e., conversions from native vegetation to pasture and from pasture to sugarcane), on C and N losses and inputs for the 0–1.0 m soil depth. Specifically, we wanted: i) to compare C and N stocks among different land uses; ii) to assess SOM alterations induced by conversions of native vegetation into pastures and then from pastures into sugarcane using C-partitioning, $\delta^{13}C$ and $\delta^{15}N$ values; and iii) to evaluate the rates of C stocks changes in pasture and sugarcane soils through the soil profile.

2. Material and methods

2.1. Description of study sites

The study sites were located in three strategic and representative locations in the south-central Brazil, the main sugarcane producing region of the world (Fig. 1). The first site, Lat_17S, is located in Jataí, southwestern region of Goiás state (Lat.: 17°56′16″S; Long.: 51°38′31″W) with a mean altitude of 800 m and a predominance of clayey Acrudox soils (USDA, 2014). The climate classification is Awa type (Köppen) mesothermal tropical, with a mean annual temperature of 24.0 °C and an annual precipitation of 1600 mm, with a dry season in the winter (May to September). The second site, Lat_21S, is located in Valparaíso, west region of São Paulo state (Lat.: 21°14′48″S; Long.: 50°47′04″W) with a mean altitude of 425 m and predominance of loamy Hapludalf soils (USDA, 2014). The climate classification is Aw type (Köppen classification) humid tropical, with rains concentrated in the summer (October to April) and a dry season in the winter (April to September). The area has a mean annual temperature of 23.4 °C and an annual precipitation of 1240 mm. The third site, Lat_23S, is located in Ipaussu, south-central region of the São Paulo state (Lat.: 23°05′08″ S; Long.: 49°37′52″ W), with a mean altitude of 630 m and predominance of clayey Hapludox soils (USDA, 2014). The climate classification is Cwa type (Köppen) tropical, with rains concentrated in the summer (October to April) and a dry season in winter (May to September). The annual mean temperature is 21.7 °C and the annual precipitation is 1470 mm. More information about soil parent material and soil classification is available in Cherubin et al. (2015).

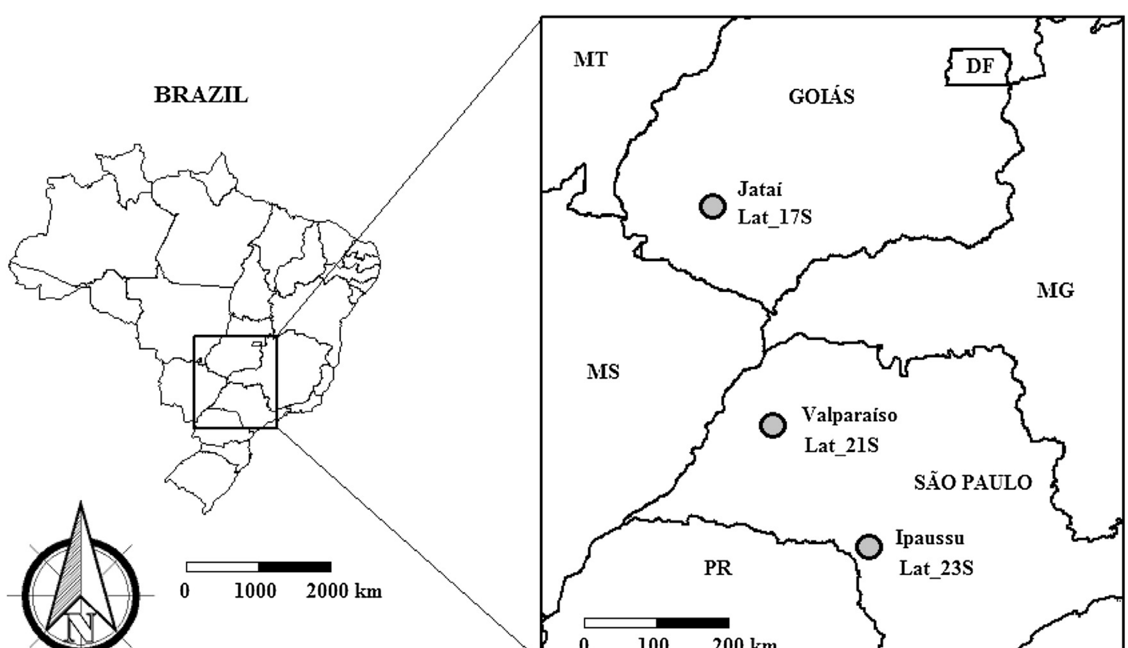

Fig. 1. Geographic location of the study sites in south-central Brazil (Cherubin et al. 2015).