Journal of Environmental Management 206 (2018) 980–988

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Impacts of sugarcane agriculture expansion over low-intensity cattle ranch pasture in Brazil on greenhouse gases

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ARTICLE INFO

Article history:
Received 6 July 2017
Received in revised form
29 November 2017
Accepted 30 November 2017

Keywords:
Land use change
GHG
Carbon dioxide
Methane
Nitrous oxide
Nitrogen fertilizer

ABSTRACT

Sugarcane is a widespread bioenergy crop in tropical regions, and the growing global demand for renewable energy in recent years has led to a dramatic expansion and intensification of sugarcane agriculture in Brazil. Currently, extensive areas of low-intensity pasture are being converted to sugarcane, while management in the remaining pasture is becoming more intensive, i.e., includes tilling and fertilizer use. In this study, we assessed how such changes in land use and management practices alter emissions of greenhouse gases (GHG) such as CO_2, N_2O and CH_4 by measuring *in situ* fluxes for one year after conversion from low-intensity pasture to conventional sugarcane agriculture and management-intensive pasture. Results show that CO_2 and N_2O fluxes increased significantly in pasture and sugarcane with tillage, fertilizer use, or both combined. Emissions were highly variable for all GHGs, yet, cumulatively, it was clear that annual emissions in CO_2-equivalent (CO_2-eq) were higher in management-intense pasture and sugarcane than in unmanaged pasture. Surprisingly, tilled pasture with fertilizer (management-intensive pasture) resulted in higher CO_2-eq emissions than conventional sugarcane. We concluded that intensification of pasture management and the conversion of pasture to sugarcane can increase the emission factor (EF) estimated for sugarcane produced in Brazil. The role of management practices and environmental conditions and the potential for reducing emissions are discussed.

1. Introduction

In 2013, the IPCC reported that atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) had reached levels about 40%, 150% and 20% above those in the pre-industrial period. Agriculture is one of the largest contributors of greenhouse gases (GHG) (IPCC, 2007a), especially because it produces relatively large amounts of N_2O and CH_4, which are potent gases (Fracetto et al., 2017; Oertel et al., 2016). Currently, approximately 66% and 49% of the global anthropic N_2O and CH_4 emissions, and 15% of the CO_2 are from agriculture (FAO, 2003). Therefore, agriculture is considered a key driver of climate change (IPCC, 2007a; Snyder et al., 2009).

The contribution of agriculture to GHG emissions is significant mainly because many commonly used practices alter key biogeochemical processes that regulate the dynamics of carbon (C) and nitrogen (N) in soils. For instance, the addition of N fertilizer to soils accelerates the N cycle (Vitousek, 1984), boosting processes that produce N_2O such as nitrification and denitrification (Pitombo et al., 2016). Tillage promotes the oxidation of organic C in soils, enhancing CO_2 emissions (REF). The process of land use change itself increases GHG emissions indirectly, but this can be just as impactful (Estavillo et al., 2002; Houghton, 2003; Fearnside et al., 2009). Unfortunately, quantitative assessments about the impacts of land use change and agricultural intensification on GHG emissions are scarce. For biofuel feedstock systems, this lack of information limits our capacity to fully assess the sustainability of

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https://doi.org/10.1016/j.jenvman.2017.11.085
0301-4797/

biofuels.

Worldwide, renewable energy sources such as biofuels are increasingly seen as a solution for the global energy crisis and climate change problems (Favretto et al., 2017). In Brazil, the second largest biofuel producer in the world, the growing demand for renewable energy in recent years has led to a dramatic expansion and intensification of sugarcane agriculture (Farrell, 2006; Fargione et al., 2008; Filoso et al., 2015; Martinelli and Filoso, 2008; Kim et al., 2009). Over the last decade alone, the area harvested with sugarcane in the country increased by about 60% (FAOSTAT, 2016), mostly at the expense of natural or unmanaged pastures (Marin and Nassif, 2013; Oliveira et al., 2016, 2017). Almost half (45%) of the expansion occurred over degraded pastures (Nassar et al., 2008). By the 2014–2015 crop season, the area planted with sugarcane in Brazil had reached 9.0 million ha, with an average productivity of 70 t ha^{-1} (CONAB, 2016).

Brazil has extensive areas of degraded or abandoned pastures (Dias Filho, 2014), hence, the expansion of sugarcane agriculture over these areas is considered to be positive because it prevents deforestation of tropical forests (Alkimim et al., 2015; Goldemberg et al., 2008). On the other hand, the loss of pasture land to sugarcane had to be counter-balanced by improving pasture productivity because cattle ranching is an important economic activity in the country, which is one of the largest producers and exporters of beef in the world (Dill et al., 2015). One option to increase productivity has been the use of grass cultivars with superior productivity. Another option has been the use of nitrogen fertilizer in pasture.

Historically, fertilizer was rarely applied to pastures in Brazil because undeveloped fertile land was easily available to cattle ranchers for relatively low prices; climate conditions are also mostly favorable in the country (Mello et al., 2014). However, nitrogen fertilizer use in Brazil has increased dramatically in recent years (ANDA, 2016), and this increase can be easily linked to growing application to pastures (FAO, 2004; Pires et al., 2015; Tiritan et al., 2016). Rates of N fertilizer application in sugarcane and other crops have increased as well.

The growing use of N fertilizer in pastures and sugarcane in Brazil can result in higher N_2O and CH_4 emissions (Estavillo et al., 2002), and change the GHG balance for sugarcane ethanol produced in the country. Conversely, adding N to soils can offset CO_2 losses and reduce GHG emissions by promoting C sequestration and storage in soils (Mello et al., 2014). Whether or not the outcome for GHG will be positive depends on a series of factors, including the type of land use conversion, the management practices implemented and on how environmental conditions affect the soil biogeochemical processes. In this context, the goal of this study was 1) to quantify GHG emissions associated with the conversion of low-intensity pasture to management-intensive pasture and sugarcane agriculture in Brazil, and 2) to determine how environmental conditions and management practices commonly used in these land uses affect emissions. Our hypothesis was that emissions of CO_2, N_2O and CH_4 would increase, but the magnitude of increase in conventional sugarcane versus managed pasture was unclear.

2. Material and methods

2.1. Study area and experimental design

The study was conducted on a dairy farm with year-round cattle grazing (Fazenda Flores, 23° 35 ′S, 47° 32′ W) in Sorocaba, southeastern São Paulo, Brazil. The region is characterized by humid summers and mild to cool winters (Köppen classification Cfa), with mean air temperatures ranging between 12 and 30 °C in the winter and summer, respectively. The average temperature in the region is 21 °C (Ikematsu et al., 2007) and mean precipitation is 1330 mm (Brazilian National Institute for Meteorology, INMET).

The experimental area was about 0.5 ha, with an average slope of 6.5% and altitude of 670 m. The dominant soil types in the region are Oxisol and Ultisol, but in the experimental area the soil type was red Oxisol with clay texture (651 g kg^{-1} clay and 17 g kg^{-1} sand). While atypical for the region, soils in the experimental area had relatively high pH and calcium concentrations (Table 1), probably because of atmospheric deposition generated from a cement factory nearby. The chemical composition of soils in the experimental area was determined from composite samples collected before fertilizer application (Table 1).

The experiments were designed to assess changes in GHG emissions from unmanaged pasture to reformed and management-intensive pasture, and sugarcane. The experimental design consisted of randomized blocks with six treatments (Table 2) and four replicates, totaling 24 experimental plots; each 10 × 7.5 m.

The plots including pasture or sugarcane without fertilizer were used to determine baseline emissions for managed pasture and sugarcane land uses. The unmanaged pasture served as a control because it represents the initial stage of pasture-to-sugarcane conversion. The unmanaged pasture in the study was about 60 years old at the time of the experiment and had never been fertilized. Pasture grazing was allowed during the experimental period but the grass was mowed several times throughout the year to prevent the production of seeds. The experiment was carried throughout the first year of the typical sugarcane crop cycle in the study region (from October to September).

2.2. Soil management practices

The first step in the implementation of conventional sugarcane agriculture and in pasture reform in the study region is conventional soil tillage. Therefore, the experimental plots in treatments T3 to T6 were first tilled before planting (Table 2). The tilling followed the recommended procedures for pasture and sugarcane in the region, which include double plowing with heavy machinery, harrowing and leveling (Passianoto et al., 2004; Pinto et al., 2004).

After tillage, plots were fertilized (October 2013) according to the recommended rates for pasture and sugarcane in the state of São Paulo (Raij et al., 1997). Pasture was fertilized using 60 kg N ha^{-1} in the form of ammonium nitrate (NH_4NO_3), 40 kg P_2O_5 ha^{-1} of superphosphate, and 40 kg K_2O ha^{-1} of potassium chloride (KCl). Sugarcane was fertilized with 60 kg N ha^{-1} as ammonium nitrate (NH_4NO_3), 140 kg P_2O_5 ha^{-1} of superphosphate, and 120 kg K_2O ha^{-1} of potassium chloride (KCl). Ammonium nitrate was used as nitrogen fertilizer because it is characteristically less susceptible to losses via volatilization when applied to the soil surfaces (Cantarella et al., 2008). Fertilizer application was done manually on 24 October 2013 over the entire pasture plots and along the rows (in furrows) in sugarcane plots.

Sugarcane was planted by burring stalks in furrows 30 cm deep along rows 1.5 m apart, which is the conventional method used in the region (La Scala et al., 2006; Ferreira et al., 2016). The sugarcane variety used was RB86-7515 (17 t ha^{-1}), which is highly adapted to the region and widely used. Sugarcane was harvested manually after 13 months (October 2014). The pasture plots were planted with *Brachiaria brizhanta* cv. Marandú (67 kg ha^{-1}) (Silva et al., 2013) sowed in late 22 October, 2013. The grass seeds took about 2.5 months to germinate and develop fully.

2.3. Sample collection and environmental parameters measurements

Gas samples were collected in each of the 24 experimental plots to quantify fluxes of CO_2, N_2O, and CH_4 during the conversion of