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Methane emissions from sugarcane vinasse storage and transportation systems: Comparison between open channels and tanks

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HIGHLIGHTS

- Vinasse is the main residue of sugarcane ethanol production.
- We quantified CH_4 emissions in the main systems of vinasse storage and transportation.
- Higher CH_4 emissions are associated with open channel systems.
- We estimated an emission of 1.36 kg CO_2 eq m^{-3} of vinasse in open channels.
- Tanks and pipes is a good strategy to mitigate CH_4 emission.

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ABSTRACT

Over the last few years the brazilian sugarcane sector has produced an average of 23.5 million liters of ethanol annually. This scale of production generates large amounts of vinasse, which depending on the manner that is disposed, can result significant greenhouse gas emissions. This study aimed to quantify the methane (CH_4) emissions associated with the two most widespread systems of vinasse storage and transportation used in Brazil; open channel and those comprising of tanks and pipes. Additionally, a laboratory incubation study was performed with the aim of isolating the effects of vinasse, sediment and the interaction between these factors on CH_4 emissions. We observed significant differences in CH_4 emissions between the sampling points along the channels during both years of evaluation (2012–2013). In the channel system, around 80% of CH_4 emissions were recorded from uncoated sections. Overall, the average CH_4 emission intensity was 1.36 kg CO_2eq m^{-3} of vinasse transported in open channels, which was 620 times higher than vinasse transported through a system of tanks and closed pipes. The laboratory incubation corroborated field results, suggesting that vinasse alone does not contribute significant emissions of CH_4. Higher CH_4 emissions were observed when vinasse and sediment were incubated together. In summary, our findings demonstrate that CH_4 emissions originate through the anaerobic decomposition of organic material deposited on the bottom of channels and tanks. The adoption of coated channels as a substitute to uncoated channels offers the potential for an effective and affordable means of reducing CH_4 emissions. Ultimately, the modernization of vinasse storage and transportation systems through the adoption of tank and closed pipe systems will provide an effective strategy for mitigating CH_4 emissions generated during the disposal phase of the sugarcane ethanol production process.

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1. Introduction

Replacing fossil fuels with sugarcane-based ethanol can reportedly reduce emissions of greenhouse gas (GHG) by around 85% (Cavalett et al., 2013; Macedo et al., 2008). Nevertheless, the magnitude of GHG reductions that can be achieved through the use of sugarcane ethanol is strongly dependent on the management practices associated with agricultural production (Davis et al., 2013) and the disposal of residues (Moraes et al., 2014). The process of obtaining sugarcane ethanol generates several residues, which depending on the manner that is disposed can result significant environmental pollution. Vinasse, also called stillage, is the most significant of these residues, both in terms of quantity and its potential environmental impacts. This residue is generated during the distillation phase of production, at an average proportion of 13 L (ranging from 10 to 15 L) for each liter of ethanol produced. Regardless of its chemical composition, vinasse contains high concentrations of organic matter, potassium and sulfates (Fuess and Garcia, 2014) and may cause serious environmental impacts, depending on the manner in which it is disposed (Filoso et al., 2015).

About 30 years ago, the ethanol industry in Brazil regulated the disposal of vinasse, specifying that it must be recycled back into agricultural fields (Filoso et al., 2015). This solution was adopted mainly because of its implicity in creating algal blooms and increasing biological oxygen demand when vinasse is discarded into watercourses (Christofoletti et al., 2013), but also because it represents the cheapest and simplest solution (Cortez et al., 1992). Thus, at present, the main way to dispose of vinasse is through direct application onto sugarcane fields.

There have been several studies addressing the agronomic benefits of vinasse fert-irrigation of sugarcane fields (Macedo, 2005; Resende et al., 2006; Parnaudeau et al., 2008; Smeets et al., 2008). More specifically, there are other studies that have emphasized the environmental impacts of this vinasse application practice (Resende et al., 2006; Carmo et al., 2013; Christofoletti et al., 2013; Oliveira et al., 2013; Fuess and Garcia, 2014; Paredes et al., 2014). However, all of these studies focus on the consequences of vinasse ferti-irrigation, but little is known about the environmental consequences resulting from the vinasse storage and transportation phases occurring prior to its field application.

In Brazil, the most common system of vinasse storage and transportation involves open channels (either uncoated or coated), in which vinasse is conveyed by gravity and active pumping (Macedo et al., 2004). Increasingly for some sugarcane mills, this system is being replaced by one composed of closed pipes and tanks. However, there is a lack of conclusive information comparing the impact of these alternative methods in terms of their respective GHG emissions. In a pioneering study, Oliveira et al. (2015) quantified the GHG emissions from vinasse flowing through an open channel in São Paulo State. The authors concluded that the storage and transportation phase is an important source of methane (CH_4) emissions to the atmosphere and should be included in future GHG inventories for sugarcane ethanol production. According to the authors, CH_4 represents about 98% of total GHG emissions released during vinasse storage and transportation, while N_2O emissions contributed on average less than 2%. However, these results represent a case study and to our knowledge, no other efforts have been made to compare GHG emissions from the two most common vinasse storage and transportation systems used in Brazil.

This study based on the hypothesis that improvements to vinasse storage and transportation systems will alter the conditions for methanogenesis and may significantly reduce GHG emissions. This research aimed to quantify emissions of CH_4 over two agricultural years, while monitoring changes in the physico-chemical characteristics of vinasse in the most widespread storage and transportation systems within the south-central region of Brazil. Additionally, we performed a laboratory incubation study aimed at isolating the individual and synergistic effects of vinasse and sediment on CH_4 emissions.

2. Methods

2.1. Field experiment

Assessments of CH_4 emissions were carried out at two commercial sugarcane mills; each representing one of the two most widespread vinasse storage and transportation systems used in south-central Brazil; i) a system of open coated and uncoated channels, and ii) a system composed of closed pipes and coated tanks. The first case study was located in the region of Bauru (22°29′32″S, 48°46′57″W) while the second was located in Piracicaba (22°38′05″S 47°41′09″O), both within the state of São Paulo. The regions in which the mills are located have similar climatic conditions (Cwa, humid subtropical) and altitudes of 520 m and 554 m, respectively in Piracicaba and Bauru regions.

2.1.1. System 1 - Coated and uncoated open channels

This system consisted of a main vinasse transportation channel, the first 40 km of which is coated with cement while the last 20 km is uncoated and vinasse is subsequently in direct contact with the soil (Fig. 1a). Both comprise of a furrow dug with a backhoe, but differ in that: i) the coated section is 1.5 m wide × 0.6 m deep and comprises the section closest to the mill; while ii) the uncoated section is 1.5 m wide × 0.7 m deep and comprises the end section of the vinasse transportation system.

Throughout the two-year evaluation period, each section of the channel system (coated and uncoated), was represented by four equidistant sampling points where CH_4 emissions were quantified.

2.1.2. System 2 - Tanks and closed pipes

In this system vinasse is stored in three coated tanks with the flow between them facilitated through closed pipes (Fig. 1b). The three tanks were ellipsoidal in shape and presented the following dimensions: Tank 1 was 25 m × 20 m; Tank 2 was 45 m × 25 m, and Tank 3 was 56 m × 30 m. The three tanks were coated with a polyethylene membrane. The vinasse is stored temporarily in these tanks and can be pumped out at high speed to the field through the closed pipes. In order to accurately quantify GHG emissions, we considered each tank as a replicate experimental unit.

2.2. Sampling and measurements of CH_4 fluxes

Methane fluxes from both vinasse storage and transportation systems were measured by obtaining gas samples as follows.

For system 1, eight sampling points were established along the main channel, four along the coated section (10 km apart from each other) and the other four along the uncoated section (5 km apart from each other). The sampling points were established at equidistant intervals along each section of the channel to better account for spatial heterogeneity and permit more accurate extrapolation of CH_4 emissions. Gas samples were obtained over two sugarcane crop seasons starting in June 2012 and finishing in December 2013, with a total of 22 sampling events.

For system 2, gas samples were taken from the center of each tank to avoid the influence of edge effects. Gas sampling in the tanks was achieved using an apparatus comprising pulleys and cables that enabled chambers to be positioned at the desired location (Fig. 2b). The sampling started during October 2012 and finished in December 2013, with a total of 16 sampling events. The