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Greenhouse gas mitigation potential from green harvested sugarcane scenarios in São Paulo State, Brazil

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ABSTRACT

Brazil is a major sugarcane producer and São Paulo State cultivates 5.5 million hectares, close to 50% of Brazil's sugarcane area. The rapid increase in production has brought into question the sustainability of biofuels, especially considering the greenhouse gas (GHG) emissions associated to the agricultural sector. Despite the significant progress towards the green harvest practices, 1.67 million hectares were still burned in São Paulo State during the 2011 harvest season. Here an emissions inventory for the life cycle of sugarcane agricultural production is estimated using IPCC methodologies, according to the agriculture survey data and remote sensing database. Our hypothesis is that 1.67 million hectares shall be converted from burned to green harvest scenarios up to years 2021 (rate 1), 2014 (rate 2) or 2029 (rate 3). Those conversions would represent a significant GHG mitigation, ranging from 50.5 to 70.9 megatons of carbon dioxide equivalent (Mt CO_2eq) up to 2050, depending on the conversion rate and the green harvest systems adopted: conventional (scenario S1) or conservationist management (scenario S2). We show that a green harvest scenario where crop rotation and reduced soil tillage are practiced has a higher mitigation potential (70.9 Mt CO_2eq), which is already practiced in some of the sugarcane areas. Here we support the decision to not just stop burning prior to harvest, but also to consider other better practices in sugarcane areas to have a more sustainable sugarcane based ethanol production in the most dense cultivated sugarcane region in Brazil.

1. Introduction

The National Alcohol Program (*Proálcool*) was established in Brazil in 1975 with the purpose of reducing petroleum imports through the production of ethanol from sugarcane. Most recently, the scientific community has recognized the environmental benefits of replacing fossil fuels with ethanol from sugarcane [1]. It is estimated that ethanol derived from 1 ha of

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sugarcane avoids the emission of about 14 tons (t) CO_2eq yr^{-1} relative to the use of fossil fuels [2]. Furthermore, when compared to ethanol derived from other feedstock (such as sugar beet, maize and sorghum), sugarcane is the most effective option in mitigating emissions of greenhouse gases (GHG) [3].

The rapid expansion of the cultivated sugarcane area in Brazil, mainly in São Paulo State [4], has left many unanswered questions about the true sustainability of biofuels [5], especially in relation to GHG emissions from the agricultural sector, which accounts for nearly 90% of the GHG footprint of sugarcane ethanol [6]. Normally, the sugarcane harvest is performed manually with preliminary burning (burned harvest), or mechanically without burning (green harvest). The burning practice aims to facilitate manual harvesting through the removal of leaves and poisonous animals. However, resultant emissions of greenhouse gases cause harm to the environment [5] and human health [7]. GHG emission from pre-harvest burning has been estimated as 941 kg CO_2eq ha^{-1} yr^{-1}, which corresponds to 30% of the total GHG emission in sugarcane production [8]; these emissions are essential in assessing the sustainability of ethanol production.

Remote sensing satellite images are an effective tool in monitoring the cultivated sugarcane area [4], and also the sugarcane harvest practice [9], allowing the generation of accurate information that can serve as a basis for studies on GHG emissions and energy balance. Since 2006, the National Institute for Space Research (*Instituto Nacional de Pesquisas Espaciais*; INPE) monitors the sugarcane harvesting practice in São Paulo State and generates monthly and annual maps of the sugarcane areas harvested with and without the pre-harvest burning. These maps have served as support for public policies on the control, supervision and cessation of burning, and can be viewed on the website www.dsr.inpe.br/laf/canasat.

Legal restrictions regarding the sugarcane pre-harvest burning, and the consequent increase of mechanical harvesting without burning influence the GHG emissions balance in agricultural areas in various forms, since the quantities of diesel and agricultural inputs (nitrogen fertilizer, vinasse, filter cake, limestone and pesticide) consumed in the crop production vary according to the management system adopted, namely with or without the burning practice. De Figueiredo and La Scala [8] reported that conversion from burned to green plot could save from 310.7 (not considering soil carbon sequestration) to 1484.0 kg CO_2eq ha^{-1} yr^{-1} (considering soil carbon sequestration).

Several agricultural management alternatives have been proposed to mitigate GHG emissions associated with the sugarcane production [10]. For this analysis, we have focused on the potential of GHG mitigation simulating the non-burning of harvest residues, as well as avoiding emissions as a result of changes in tillage practices and introducing crop rotation in all production areas where sugarcane is still harvested with burning. To reduce the negative environmental impacts of biofuels production in Brazil, and taking into account the sources and sinks of carbon in the sugarcane production process, this study aimed to estimate the potential for GHG mitigation in the agricultural sector from the year of 2012 until 2050, in response to the conversion from burning to green harvested management scenarios (conventional or conservationist), based on three conversion rates, in São Paulo State.

2. Material and methods

2.1. Sugarcane production and management scenarios for 2050

Sugarcane crop yield is related to edaphoclimatic conditions, cultural practices and adopted varieties, corresponding to approximately 82 t of cane per hectare in São Paulo State [11]. On average, sugarcane has a full crop cycle of six years, during which five harvests, four ratoon treatments, and one field renovation are performed. The first harvest is usually done 15–18 months after planting. The harvest of the ratoon is done once a year for four consecutive years, on average. After the first harvest, yield tends to reduce from year to year, making the renovation of the sugarcane field with a new planting necessary after a typical frequency of four harvests [12].

Traditionally, conventional soil tillage is adopted during sugarcane field renovation, which consists of the mechanical removal of ratoon, followed by the operations of subsoiling, heavy harrow, medium harrow, and grader harrow. Recently, conventional tillage has been replaced by reduced tillage in some regions in Brazil, where the soil is lightly tilled in the planting row [13]. To improve fertility and physical properties of the soil, the introduction of crop rotation with leguminous is an agricultural practice widely used during sugarcane field renovation [14].

This study was based on an estimate of the potential mitigation of greenhouse gases (GHG) emissions in São Paulo State during the period from 2012 to 2050, in sugarcane areas where manual harvesting with burning and conventional soil tillage are still practiced (scenario S0). The management scenarios proposed in this study take into account the conversion of the system of manual harvesting with burning for mechanized harvesting without burning (green harvest), including the adoption of conservationist management practices in the sugarcane agricultural production.

The scenario S1 refers to the system of green mechanized harvesting that uses conventional soil tillage during sugarcane field renovation, and the scenario S2 corresponds to the system of green mechanized harvesting that uses reduced soil tillage plus the introduction of a crop rotation (*Crotalaria juncea* L.) during sugarcane field renovation. We assumed a crop cycle of six years, so that in scenarios S0 and S1, the soil remained in fallow until the new sugarcane is planted (six months), and in scenario S2, crop rotation with *C. juncea* L. was introduced in the same period. The estimates of the GHG emissions for production scenarios were calculated in accordance with the IPCC methodologies [15] and expressed in kg CO_2eq ha^{-1} yr^{-1} following the global warming potential (GWP) of each gas for a period of 100 years, which is 1 for CO_2, 25 for CH_4 and 298 for N_2O [16].

2.2. Remote sensing data and harvest conversion rates

The calculation of GHG mitigation potential of converting the type of sugarcane harvest in São Paulo State was based on the area harvested with burning during the 2011 harvest season that was mapped based on visual interpretation of Landsat type satellite images acquired from April to December of each