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Modeling approaches for agricultural N_2O fluxes from large scale areas: A case for sugarcane crops in the state of São Paulo - Brazil

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ABSTRACT

Anthropogenic greenhouse gas (GHG) emissions and climate change are issues that currently receive a great deal of attention, both from society and the scientific community. Combustion of fossil fuels is considered the main reason for the increasing concentrations of GHG in the atmosphere and therefore, the main cause of climate change. In such context, biofuels are usually presented as an energy source that considerably reduces GHG emissions when compared to the use of fossil fuels. However, some issues of biofuel production such as the emissions associated with both change in land use and the use of nitrogen fertilizers are still under scrutiny. The focus of this study is related to N_2O soil emissions associated with sugarcane ethanol production in Brazil. Signatory countries of the United Nation's Framework Convention on Climate Change (UNFCCC) are required to prepare and periodically update an inventory of GHG emissions and sinks. The International Panel of Climate Change (IPCC), through the Agriculture, Forest and Other Land Use (AFOLU), establishes guidelines to calculate N_2O soil emissions on three different levels, or tiers. The simplest Tier 1 uses few equations and default emissions factors. The most elaborated, Tier 3, uses computation modeling, field measurements and Geographic Information Systems (GIS). This study proposes using the limited data available, procedures for Tier 3 estimates of N_2O soil emissions in sugarcane crops in the state of São Paulo - Brazil. It also compares N_2O sugarcane emissions calculated by Tier 1 and Tier 3 methods. Results show that in most cases the difference in results from Tier 1 and Tier 3 methods are beyond the error margin of the Brazilian Inventory.

1. Introduction

Currently, there is great concern with anthropogenic greenhouse gas (GHG) emissions. Since the industrial revolution, the concentration of such gases in the atmosphere has increased considerably and the present rate of fossil fuel consumption is considered the main cause of global warming due to the high levels of greenhouse gas emissions associated with this practice (Sims, 2004). This climatic change is considered one of the most serious environment threats throughout the world because of its potential impacts on food production and processes vital to a productive environment (Pimentel et al., 1994). In such context, ethanol fuel is presented as a sustainable source of energy, with reduced GHG emissions.

There is still strong debate about the real benefits in terms of GHG emissions provided by the use of ethanol fuel. Its use is supported by some scientific publications (Farrell et al., 2006; Goldemberg, 2007; Macedo et al., 2008; La Rovere et al., 2011) but also criticized by some authors (De Oliveira et al., 2005; Pimentel et al., 2007; Fargione et al., 2008; Searchinger et al., 2008). Certain aspects of the life-cycle GHG emissions associated with ethanol fuel production, such as land use change and soil N_2O emissions, are still under scrutiny. In spite of such controversy, Brazilian ethanol production experienced a new increase in production during the first decade of the 21st century.

Agriculture however, is an important source of greenhouse gases (GHG), especially N_2O and CH_4, with the latter being usually associated with rice cultivation and cattle production. In 2005, 10 to 12% of anthropogenic GHG emissions derived from agricultural activities. Of global anthropogenic emissions in 2005, agriculture accounted for about 60% of N_2O emissions (IPCC, International Panel on Climate Change, 2007). It is known that the global warming potential (GWP) of N_2O is about 300 times larger than of CO_2 (Schlesinger, 1997). Besides its importance as a GHG, N_2O released to atmosphere has other relevant environmental consequences. The molecule of N_2O is extremely stable, for this reason, N_2O emitted at the troposphere reaches the stratosphere where it contributes to the destruction of the ozone (O_3) layer. The only known significant mechanism of N_2O removal occurs in the stratosphere and consists of the photolytic oxidation of N_2O into NO, which reacts with O3, destroying it (Schlesinger, 1997). The stratospheric ozone layer

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absorbs virtually all the solar ultraviolet radiation of wavelengths between 240 and 290 nm. Such radiation is harmful to unicellular organisms and to surface cells of higher plants and animals. In addition, ultraviolet radiation in the wavelength range 290–320 nm, so-called UV-B, is biologically active. A reduction in stratospheric ozone leads to increased levels of UV-B at the ground level, which can lead to increased incidence of skin cancer in susceptible individuals. An approximate rule of thumb is that a 1% decrease in stratospheric ozone leads to a 2% increase in UV-B radiation in the ground (Seinfeld and Pandis, 2006).

Given their importance, the International Panel on Climate Change (IPCC) has a specific chapter dedicated to estimations of GHG emissions from agriculture. The IPCC guidelines for GHG inventories derived from agricultural activities include among others, procedures for estimating direct and indirect N_2O emissions from soils and N_2O emissions from the burning of residues. In this study we are particularly interested in direct N_2O soil emissions occurring at the regional scale.

The Agriculture, Forest and Other Land Use (AFOLU), guidelines for emissions inventories consider three different levels or "tiers" for emission calculations. The Tier 1 method is the easiest to use, whose equations are simple and default values are used for some parameters. As an example we can cite the default emission factor (EF) value for N_2O emissions associated with the use of mineralized fertilizers (0.01 kg N_2O —N (kg N input)$^{-1}$). Tier 2 uses mostly the same methodological approach as Tier 1, but the values for emissions factors are based on regional data. Tier 3 uses more elaborated methodologies such as computational modeling and includes comprehensive field measurements and Geographical Information Systems (GIS) for soil, land use and land management data (IPCC, International Panel on Climate Change, 2006). AFOLU considers the Tier 3 approach to have greater certainty than the lower level methods. The United States Environmental Protection Agency (EPA) makes use of the Tier 3 approach for estimating direct N_2O emissions from major crops in mineral (non-organic) soils. The DAYCENT ecosystem model (Parton et al., 1998; Del Grosso et al., 2002) is used to estimate emissions from corn, soybeans, wheat, alfalfa, hay, sorghum and cotton, which represent approximately 90% of total croplands in the United States (USEPA, United States Environmental Protection Agency, 2010).

Brazil has published two inventories for agricultural emissions which were prepared at the Tier 1 level. They are based mostly on the "Revised 1996 Guidelines for National Greenhouse Gas Inventories". However, as pointed out by MCT (Ministério da Ciência e Tecnologia – Brasil) (2002), the IPCC use as reference researches and methods formulated by experts in developed countries where fossil fuel burning emissions are more important than the ones related to agriculture and land use change. Therefore, default values or even the methodology itself have to be carefully evaluated. Computing such emissions for inventories however is considerably challenging since these are non-point emissions occurring at the regional scale and the inventories encompasses emissions of large geographical areas. Hence, national-scale inventories present a series of limitations since it is almost impossible to account for the diversity of agricultural management practices of large geographical areas, not to mention the diversity of climatic and pedological conditions that might be required for emission calculations. MCT (Ministério da Ciência e Tecnologia – Brasil) (2002) states that in Brazil, given its costs, data collection and storage are inadequate and there is little institutional concern for providing or organizing such information.

Since inventories can serve as basis for development of environmental policies, the objective of this paper is to propose with the limited data available, a procedure for creating an inventory of agricultural GHG based on computational modeling and GIS. This procedure was applied to estimate soil N_2O emissions of sugarcane crops in the state of São Paulo, the most important sugarcane and ethanol producer in Brazil. This study is also interested in observing how spatial resolution might affect these emissions estimates; therefore, the procedure will be applied at different spatial scales.

Estimates of soil N_2O emissions from sugarcane crops based on IPCC's Tier 1 approach methodology were also performed and the results of the two methods were compared.

We consider the major contribution of this study, to be the provision of the first framework towards the development of Tier 3 inventories for N_2O agricultural emissions, for the state of São Paulo and also for the country.

2. Material and methods

2.1. Area and period of study

The chosen area of study was the state of São Paulo, historically the greatest sugarcane and ethanol producer in Brazil. The latest available data for the year 2012 indicates that 53% of Brazilian sugarcane is cultivated in São Paulo (www.sidra.ibge.gov.br). During the last decade, thanks to the revitalization of ethanol production, the sugarcane planted area in São Paulo increased from approximately 3 to 5.3 million hectares (ha). Due to data availability, this study refers to the period from the 2003/2004 to 2010/2011 harvest seasons.

2.2. GHG computational model

We emphasize the fact that for the method proposed in this study, any GHG emissions computational model can be used. Our choice was the Denitrification Decomposition model (DNDC), obtained directly with its developer. It has been extensively validated (Li, 2000; Tonitto et al., 2007; Giltrap et al., 2010) and also accounts for CH_4 emissions, which are also of interest, but the subject of a separate study.

DNDC is a process-oriented model that simulates carbon and nitrogen biogeochemistry in agricultural ecosystems. The model has two components. The first one consists of soil climate, crop growth, and decomposition sub-models and predicts soil temperature, moisture, pH, redox potential (Eh) and substrate concentration profiles influenced by ecological drivers (e.g., climate, soil, vegetation and anthropogenic activity). The second component consists of the nitrification, denitrification and fermentation sub-models and predicts emissions of carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), nitric oxide (NO), nitrous oxide (N_2O), and dinitrogen (N_2) from the plant-soil systems (Li, 2000).

2.3. GIS and DNDC

The purpose of GIS in this research is to assist in the choice of data inputs to run the DNDC model. These inputs are based on soil types, location of sugarcane crops, watersheds, climate and spatial scales. Although DNDC has a module that allows the use of a GIS database, this option was considered impractical for this study given the characteristics of the available data.

The GIS software employed was the ArcGIS – version 10.1, developed and commercialized by "Environmental Systems Research Institute" – Esri - Redlands, (CA).

To perform this study, initially it was necessary to precisely establish the location of sugarcane crops in the state of São Paulo. The maps with such locations were provided by a project from the Brazilian Institute of Spatial Research (INPE), named "Canasat" (http://www.dsr.inpe.br/laf/canasat). This project monitors sugarcane crops in the Southern center part of Brazil through satellite images (Rudorff et al., 2005; Rudorff et al., 2010). The maps obtained provided not only the location of the crops, but also classified them in four categories: ratoon, expansion, reformed, and plant. The ratoon sugarcane corresponds to crops that were harvested at least once, that is, sugarcane which grows from the stubble left behind after harvesting. Expansion corresponds to new areas where sugarcane is growing for the first time. Reformed and plant correspond to areas with new sugarcane shoots growing from freshly planted sets. Also available from the "Canasat" project are maps indicating the crop