Atmospheric Environment 136 (2016) 123–133

Contents lists available at ScienceDirect

Atmospheric Environment

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

Quantifying nitrous oxide emissions from sugarcane cropping systems: Optimum sampling time and frequency

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HIGHLIGHTS

- Year-long sub-daily N_2O emissions data from 3 sites used to assess sampling strategy.
- Sampling in daytime between 09:00 and 12:00 best estimated daily mean N_2O emissions.
- Weekly sampling + biweekly sampling for one week after >20 mm rainfall most efficient.
- Applying sampling recommendations will reduce errors in manual chamber measurements.
- Sampling schedules achieve greater accuracy in higher emission systems.

ARTICLE INFO

Article history:
Received 18 November 2015
Received in revised form
6 April 2016
Accepted 6 April 2016

Keywords:
Nitrous oxide
Diurnal variation
Sampling frequency
Sugarcane
Static chamber
Temporal variability

ABSTRACT

Nitrous oxide (N_2O) emissions from soil are often measured using the manual static chamber method. Manual gas sampling is labour intensive, so a minimal sampling frequency that maintains the accuracy of measurements would be desirable. However, the high temporal (diurnal, daily and seasonal) variabilities of N_2O emissions can compromise the accuracy of measurements if not addressed adequately when formulating a sampling schedule. Assessments of sampling strategies to date have focussed on relatively low emission systems with high episodicity, where a small number of the highest emission peaks can be critically important in the measurement of whole season cumulative emissions. Using year-long, automated sub-daily N_2O measurements from three fertilised sugarcane fields, we undertook an evaluation of the optimum gas sampling strategies in high emission systems with relatively long emission episodes. The results indicated that sampling in the morning between 09:00–12:00, when soil temperature was generally close to the daily average, best approximated the daily mean N_2O emission within 4–7% of the 'actual' daily emissions measured by automated sampling. Weekly sampling with biweekly sampling for one week after >20 mm of rainfall was the recommended sampling regime. It resulted in no extreme (>20%) deviations from the 'actuals', had a high probability of estimating the annual cumulative emissions within 10% precision, with practicable sampling numbers in comparison to other sampling regimes. This provides robust and useful guidance for manual gas sampling in sugarcane cropping systems, although further adjustments by the operators in terms of expected measurement accuracy and resource availability are encouraged. By implementing these sampling strategies together, labour inputs and errors in measured cumulative N_2O emissions can be minimised. Further research is needed to quantify the spatial variability of N_2O emissions within sugarcane cropping and to develop techniques for effectively addressing both spatial and temporal variabilities simultaneously.

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1. Introduction

Nitrous oxide (N_2O) is a potent greenhouse gas, with a global warming potential 298 times that of carbon dioxide and is also the main contributor to the depletion of ozone in the stratosphere

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http://dx.doi.org/10.1016/j.atmosenv.2016.04.008
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(Ravishankara et al., 2009). Increases in the concentration of atmospheric N_2O have been largely attributed to increases in usage of nitrogenous fertilisers and organic amendments applied to soils (Davidson, 2009). Soil microbes utilise mineral nitrogen (NH_4^+ and NO_3^-) generated from the nitrogenous inputs during the nitrification and denitrification processes and emit N_2O as a by-product or intermediate. Loss of nitrogen (N) as N_2O, which is often accompanied by dinitrogen loss during denitrification, is also an economic cost, either as a direct loss of purchased fertiliser N or as a loss in potential yield. Therefore there are both environmental and economic interests in measuring N_2O emission from cropped soils, with the ultimate goal of reducing N_2O losses and increasing fertiliser N use by crops.

Measurements of N_2O emissions from soils, until recently, relied heavily on the manual static chamber method (Parkin and Venterea, 2010; Dalal et al., 2003). This method generally employs a collared base inserted into the soil, with an air tight enclosure placed on the collar only during sampling. Using a syringe, a series of samples are extracted from the enclosed headspace over a period of time (~0.5–2 h), injected into vials and then transported to a laboratory for analysis. Benefits of this method for agricultural field trials include the ability to accommodate large numbers of replications, low initial setup costs and simple deployment. Due to the time required to sample and often the travel time to and from field sites, the manual static chamber method is labour and time intensive, therefore limiting the frequency of sampling. Furthermore, the majority of recent N_2O studies employing manual chambers have taken measurements during mid-morning and assumed this is an appropriate time of day to sample (Bell et al., 2015; Hinton et al., 2015; Yang et al., 2015; Zhou et al., 2015). This is even though some studies have reported large underestimations of up to 43% of the mean seasonal N_2O emissions when sampling occurred mid-morning (Scheer et al., 2012). Infrequent sampling has the potential to overlook both diurnal variability and day to day variability, and subsequently is considered one of the major disadvantages of this method.

In contrast to manual static chambers, automated static chamber systems allow measurement of emissions at a sub-daily frequency. The automated sampling systems generally conduct analysis in-situ, and thus are less labour- and time-consuming. However, they are often limited to a set number of chambers and have high setup costs; their reach within a field trial is constrained by the length of sample lines; and site selection is limited by power availability.

The sub-daily data collected by automated chamber systems can provide a basis on which to asses optimum sampling strategies for manual static chambers, and to reduce any biases and inaccuracies caused by discontinuous samplings. The majority of previous assessments from sub-daily data have evaluated fixed sampling intervals from 1 to 31 days (Morris et al., 2013; Liu et al., 2010; Parkin, 2008). However, strategic samplings based around high emission events such as rainfall and fertilisation, may offer more accurate estimations of cumulative N_2O emissions with reduced labour inputs in field studies (Barton et al., 2015; Reeves and Wang, 2015). Therefore an assessment of event based sampling strategies is required to give certainty to, and provide improvements for, future sampling regimes.

Sugarcane is cropped on over 28.7 million hectares of land globally (FAO, 2015). Sugarcane farms are all located in wet and warm tropics and subtropics and generally emit large amounts of N_2O, in the range between 1.5 and 45.9 kg N_2O-N/ha/year (Soares et al., 2015; Wang et al., 2016; Denmead et al., 2010). Therefore accurate measurement of N_2O emissions from sugarcane is of importance. Strategic rainfall-based sampling regimes have previously been assessed in a wheat cropping system (Reeves and Wang, 2015), an unfertilised pasture and rainforest (Rowlings et al., 2015) in Australia and a grazed pasture in New Zealand (Van Der Weerden et al., 2013). Conclusions from previous studies have been contrasting with daily, three times a week and various different strategic schedules being recommended, which is evidence that in different systems different sampling strategies may be required (Barton et al., 2015; Reeves and Wang, 2015; Van Der Weerden et al., 2013). Furthermore, the most comprehensive assessment of fixed sampling schedules to date, at nine sites, did not include any sugarcane cropped sites and indeed advocated further assessments in different agricultural and environmental systems (Barton et al., 2015). The lack of representation of sugarcane cropping systems in previous sampling frequency assessments needs to be addressed, as N_2O emissions from sugarcane cropped soils exhibit lower episodicity, which could impact the sampling frequency required. The large nitrogen fertiliser inputs (typically between 120 and 230 kg/ha in Australia) shortly before the wet and warm summer season cause a distinct prolonged high N_2O emission period over spring and summer. This would justify implementation of a focused sampling strategy around high rainfall periods, that can reduce the overall number of sampling days with minimal loss of accuracy in measured annual N_2O emissions.

With this in mind, the objective of the study is to determine the most temporally efficient and effective sampling strategies when using static chambers to quantitatively measure N_2O emissions from sugarcane fields. This study uses year-long sub-daily data from three sugarcane sites to assess (i) the time of day which best approximates the daily mean N_2O emission rate, and (ii) simulate a number of different sampling regimes, including both fixed and rainfall based, to ascertain the most effective and efficient sampling frequency to estimate annual cumulative N_2O emissions.

2. Methods

2.1. Experimental sites and treatments

Sub-daily N_2O emissions were measured at three sites located on the eastern coastline of Australia, ranging from southern to northern Queensland (Fig. 1). All experiments were established as a randomised block design with multiple treatments, consisting of different fertiliser rates, fertiliser types, and management practices (Wang et al., 2015, 2014, 2012). At each site, due to a limited number of automated chambers and length of sampling lines, only two treatments were measured for N_2O emissions using an automatic sampling system. One treatment had no fertiliser addition and the other was a treatment with N fertiliser added at recommended rates as urea (140–150 kg N/ha). For the purposes of this study, only the fertilised treatment was used, as it had higher emissions, which would elucidate diurnal and daily changes better than the nil fertiliser treatment.

Site 1 was located on a sugarcane farm in the sub-tropics at Bundaberg, Queensland (24°57′ S, 152°20′ E). After a five year cane cycle, and a 12 month period of fallow, sugarcane was planted in single rows on raised beds. Urea fertiliser was added at a rate of 25 kg N/ha at planting on 2 September 2013, with an additional 120 kg N/ha side-dressed and buried to about 10 cm approximately two months later. Measurements of N_2O emissions from 4 September 2013 to 15 September 2014 were used in the present study, totalling 376 days. The crop was harvested on 16 September 2014. Green cane trash blanketing (GCTB), the retention of crop residues on the soil surface after harvest, was practised from 2007 to 2012. The long-term (1981–2010) annual mean temperature is 21.8 °C (Bundaberg Aero Station, the Bureau of Meteorology, Australia), with the lowest monthly mean temperature in July (16.6 °C) and the highest in January (26.1 °C) (Fig. 1). Mean annual

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