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Atmospheric Measurement Techniques Discussions

Interactive comment on "Capturing temporal heterogeneity in soil nitrous oxide fluxes with a robust and low-cost automated chamber apparatus" *by* Nathaniel C. Lawrence and Steven J. Hall

Nathaniel C. Lawrence and Steven J. Hall

stevenjh@iastate.edu

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We thank the reviewer for their thoughtful comments, which we address below. For the editor's convenience, the line numbers in our quoted text refer to the revised manuscript version which we will submit

Anonymous Referee #2 Received and published: 29 April 2020 An interesting and useful paper outlining a relatively simple and robust technique for automated field chambers. Only a few minor comments on the operation and design of the cham-

bers themselves, but I'd like to see more discussion around the construction labour costs (important if claiming "low cost" but not including them in the budget) and also the availability/cost of replacement parts - particularly if these are custom built.

Response: Good point. We had noted the manufacturers of the major components in the original manuscript but we have now presented all of this information more explicitly in a table of chamber component cost, supplier, and use which has been added as Appendix A. We have also included estimates of labor hours for construction/assembly (labor costs would vary greatly depending on the wage of the person doing the work) along with a more detailed enumeration of materials costs.

L473: "Despite these challenges, we were able to construct and maintain 8 (+1 spare) high-frequency automated chambers for sub-daily N2O and CO2 flux measurements in a temperate agricultural field, with a total materials cost (∼$40,000 US dollars, including parts for 9 chambers, gas analyzers, control system, and power supply) that is a fraction of the cost of many laser-based N2O analyzers alone. We estimate that the chambers and control system took us 130–260 hours in total to construct and troubleshoot (with concomitant labor/salary costs) and did not require specialized tools beyond those available in a typical workshop."

Some comment on the technical requirements for the data analysis would also be useful for handling such a large dataset.

Response: Good Point. We amended section 2.5 "Measurement Principle" to describe ancillary data files that will accompany the final manuscript to describe these analyses. We are providing our datalogger and analysis code associated with this paper in a public repository at Iowa State University (doi to be assigned following manuscript acceptance).

L292: "All data cleaning, flux calculation, and data analysis were conducted with R statistical software version 3.6.1 (R Core Team, 2019). Cleaning and calibration required R packages lubridate, nlme, and reshape (Spinu, 2020; Wickham, 2018; Willigen, 2020). The CR3000 datalogger code we used to operate the chambers and record data, along with an example dataset and R script for data cleaning and flux calculations, are provided as archived files associated with this publication."

Other comments: Introduction line 63. Some references to these other measurement types are required here.

Response: We have amended this to include reference to more measurement types, including GC systems.

L66: "Chambers have been paired with analyzers to measure other trace gases, including N2O and CH4, by utilizing methods such as gas chromatography (GC), photoacoustic infrared detection, tunable diode laser (TDL), or cavity ring-down laser spectroscopy (Ambus and Robertson, 1998; Breuer et al., 2000; Courtois et al., 2019; Papen and Butterbach-Bahl, 1999; Pihlatie et al., 2005)."

Line 65: There are a lot of automated systems that use GC's as well which need to be referenced here. These are also relatively inexpensive ((<$20,000 USD) compared to the lasers and have been used in extreme environments (e.g. Wolf 2010 in Inner Mongolia and Kiese 2003 in tropical rainforests). These need to be mentioned as existing options.

This is a relevant point, but we note that whereas chamber systems themselves may be < $20,000, we are unaware of any modern gas chromatographs (with electron capture detector for N2O analysis) that can themselves be purchased for less than many tens of thousands of dollars. We have added GC measurement systems (as described above) and cited additional studies to demonstrate applications of each analyzer type. We also expanded a paragraph in the Introduction to cover more analyzer options and details.

L61: "Prefabricated automated chambers capable of measuring soil trace gas fluxes are available commercially and can be plumbed to a wide range of analyzersâĂŤ-

most commonly, infrared gas analyzers that measure CO2. Commercially available chambers typically rely on electric components for movement which are sensitive to moisture, and they are substantially more expensive (often many thousands of USD) than the chamber design described here (materials costs of ~500 USD/chamber). Other custom-built chamber designs have been developed to address specific research needs (Ambus and Robertson 1998; Butterbach-Bahl et al., 1997; Savage et al., 2014). Chambers have been paired with analyzers to measure other trace gases, including N2O and CH4, by utilizing methods such as gas chromatography (GC), photo-acoustic infrared detection, tunable diode laser (TDL), or cavity ring-down laser spectroscopy (Ambus and Robertson, 1998; Breuer et al., 2000; Courtois et al., 2019; Papen and Butterbach-Bahl, 1999; Pihlatie et al., 2005). Fassbinder et al. (2013) provide a detailed summary of the advantages and limitations of each analyzer option that we briefly summarize here. GC systems equipped with electron capture detectors (ECD) have been used to measure N2O from automated chambers (Breuer et al., 2000; Papen and Butterbach-Bahl, 1999). However, GC systems have high power demand and require carrier gases and radioactive elements for ECD operation that may limit their field practicality. Interference by water vapor potentially limits the use of photoacoustic analyzers in the field (Ambus and Robertson, 1998; Fassbinder et al., 2013). Laser-based analytical approaches such are capable of rapid (e.g. 10 Hz) and precise N2ÂňO measurements, but these analyzers may be prohibitively expensive (>70,000 USD) and also have relatively high power requirements for autonomous field deployment (Fassbinder et al., 2013; Pihlatie et al., 2005). We sought to implement a lower-cost, solar powered, soil gas flux measurement system capable of operating unattended in a harsh field environment, and where analyzers could feasibly be replaced if stolen or damaged. For these reasons, we utilized a gas filter correlation (GFC) infrared N2O analyzer in our study (~16,000 USD), similar to that described previously by Fassbinder et al. (2013), along with an infrared gas analyzer for CO2/H2O measurement (~4,000 USD). However, other analyzers could be readily employed with the chamber and manifold system described below."

Line 125: Clarify that these measurements are referring to the frame and not the "collar". Chamber base and collar are both often used to describe the same thing

Response: Good point. In the context of this paper, frame refers to the stainless-steel tubing while “base” refers to the plastic structure that the frame is attached to. This has been clarified in section 2.2 “Chamber Design”.

L147: “Here we define the chamber base as the rigid, rectangular polyethylene structure (Figure 3a) and the chamber frame as the metal structure superior to the base which allows for movement of the chamber lid (Figure 3). The chamber collar is defined as the length of polyvinylchloride (PVC) pipe that forms the interface between the chamber lid and the soil.”

Line 167: I imagine this would be a major limitation in highly shrink/swell soils such as vertisols, or large vigorous crops (please comment)

We now clarify that these soils did in fact contain swelling clays, albeit not to the extent of a true Vertisol. We found that pounding rebar into the soil on either side of the chamber base and affixing the frame to the rebar (described in the text below that referenced in this comment) addressed problems associated with chamber movement. This solution is noted in section 2.2 “Chamber Design”. Application of this method in true Vertisols could likely be achieved by deeper installation of rebar to secure the chamber. We periodically checked that the chamber lids were effectively sealing against the collars. See clarified text:

L190: “However, we found that pressure exerted by the pneumatic arm when opening or closing the chamber occasionally shifted the position of the chamber base or collar and prevented a seal between the chamber lid, collar, and soil. This occasionally occurred following tillage or when soils were extremely dry, given that these soils contained swelling clays. To address this problem, we anchored the chamber base using two steel rebar rods (60 cm length, 1.27 cm diameter) pounded 45 cm into the ground on either side of the chamber base and affixed to the outside of the chamber base

with U-bolts positioned along the central axis of the collar (Fig. 3). We periodically checked that the chamber lids were effectively sealing against the collars. Application of this method to true Vertisols, with even greater shrink/swell behavior, could likely be achieved using similar use of rebar to anchor the chamber.”

We acknowledge that vegetation can be a challenge for chamber-based measurements. We added details about how we dealt with vegetation management in section 2.1 “Study Site”

L131: “Chambers were placed immediately adjacent to crop plants; due to frequent tillage and herbicide application, recruitment of other plants inside the chamber collars was uncommon, but any plants were removed from the chamber interiors as soon as they were observed. Roots from crop plants were not excluded and likely grew beneath chambers."

Line 195: What diamter and material is used for the chamber lines (I may have missed elsewhere)

Response: This was unclear, good point. The pressurized tubing details are noted in section 2.3 “Chamber Lid Operation”. The chamber lines are the same material, we have added the material details to section 2.4 “Principles of chamber gas sampling" as well to make that more clear.

L200: “We used 0.64 cm OD, 0.43 cm ID low-density polyethylene (LDPE) plastic tubing. We initially used aluminum composite tubing (Synflex 1300), which has been commonly used in other field trace gas measurement studies (e.g. Bowling et al. 2015), but we found this to be impractical for our application given its vulnerability to kinking during chamber installation and removal through dense vegetation.”

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