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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

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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 #1 Received and published: 18 April 2020 The authors present here a significant promise in implementing low-cost but robust automated chambers for intensive temporal soilborne GHG flux measurements. The paper describes the

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details of the hardware of chamber design, chamber operation, measurement principles, troubleshooting, and data to support the sound functioning of the design. Given the high temporal variability, especially for N2O fluxes, high-resolution measurements are critical and often achieved by automated chambers. However, their use has been limited due to the expensive nature of the technology. Therefore, âĹij$40,000 USD for 16 automated chambers with the level of accuracy and robustness as shown in this study is a significant development. This could lead to greater adoption of automated chambers to curb the uncertainty of N2O flux estimates. Therefore, I think the paper should be published in AMT.

Response: We appreciate the reviewer's interest in our manuscript.

I have listed a few questions and suggestions below for the authors' consideration. 1) I was a little confused about how many chambers were closed at a time. For example, with âĹij30 min closure period/chamber, only eight chambers could be measured in a four-hour sampling loop. A bit more clarification could be helpful. Also, how did you program the sequence of chamber closure (chamber #1 to 16) during each sampling loop? Was it random or fixed? This might impact bias.

Response: Good point. Section 2.5 "Measurement Principle" has been amended to clarify chamber closure with 16 chambers and chamber measurement sequence.

L252: "When sixteen chambers were deployed, a new chamber was closed every fifteen minutes and two chambers were closed simultaneously with the sample gases vented during a 15-minute equilibration period prior to a 15-minute measurement period. Here we describe the eight-chamber arrangement. To reduce possible conflation between measurement time and plot topographic position, we chose a consistent but staggered measurement sequence for each four-hour period (1, 5, 3, 7, 2, 6, 4, 8), where plot one was the lowest topographic position. When sixteen chambers were deployed, the plot sequence was maintained so paired chambers at each plot were measured in a single half-hour cycle."

We also added text in section 2.4 “Principles of Gas Sampling” to briefly explain the mechanics of how the chamber sample selection was modified to accommodate more chambers.

L236: “To operate sixteen chambers without reducing measurement period or frequency, separate parallel selection manifolds, additional mass flow controllers for chamber inlet/outlet, and diaphragm pumps were added. Two additional solenoid valves on the sample selection manifold allowed selection between each of the two inlet and outlet manifolds.”

2) One potential pitfall of automated chambers operating at a sub-daily scale is that they can keep the chamber close for a substantial amount of time in a day that can intercept the rainfall. This can impact soil moisture content inside the chamber relative to outside soils. However, this design reduces the closure period to 30 min (usually 45 min to 1 hour in other designs). With 6 sampling loops (4 hours long each), this could keep the chambers closed for 3 hours a day. I am interested to know if this design can be programmed in such a way to not close the chamber when there is rainfall/precipitation happening to allow the water inside the chamber?

Response: This is a good point that bears addressing in further detail in subsequent work. Potential impacts of chambers on soil moisture are one limitation of any chamber method. In principle, a voltage signal from a rain gauge could be easily programmed to signal the chambers to remain open during rainfall events as implemented by Butterbach-Bahl and Dannenmann (2011). We are providing our datalogger code associated with this paper in a public repository at Iowa State University (doi to be assigned following manuscript acceptance), which illustrates the method by which chamber movement is controlled and could be modified. However, there are logistical complications of this approach. In our region, prolonged low-intensity rainfall events are common, and this could result in long periods of time (many hours to days) without any measurements. Including a rainfall rate threshold (i.e. >0.25 cm in a measurement period) required to open chambers could limit the frequency and duration of data gaps.

Reducing the measurement frequency or measurement period would also limit the proportion of time that the chambers are closed. Both solutions would limit the amount of data collected. We plan on quantifying the magnitude of any soil moisture effect of chamber closure in our ongoing work. A description of this issue has been added to section 3.1 “Troubleshooting” including a citation to a more detailed discussion of the issue.

L351: “During periods of chamber closure (3 out of every 24 hours during typical operation), rainfall was excluded from the chamber enclosure, which could potentially alter soil moisture. Elsewhere, a rain gauge has been used to signal automated chambers to remain open during rainfall events (Butterbach-Bahl and Dannenmann, 2011). Here, we elected to maintain a consistent measurement schedule irrespective of rainfall, due to the logistical challenges posed by prolonged rainfall events (when no measurements would be collected). A rainfall rate threshold to open the automated chambers could limit the frequency and duration of data gaps in future studies.. Future measurements will quantify the potential magnitude of any soil moisture effect associated with our auto-chamber system. To reduce the duration that the chambers were closed when the system was off for power conservation or maintenance, we either left the compressor on and the chambers in the open position, or propped the chambers open.”

3) A table outlining side-by-side similarities and differences (pros and cons) with other automated systems would be interesting. I understand that the authors have discussed that here and there, but a summary would be helpful.

Response: Good point. Text has been significantly expanded in section 1 “Introduction” (lines 61-81) summarizing the benefits and limitations of various analyzer/chamber options in field settings, along with citations describing these approaches. We did not provide an explicit table in the manuscript because this issue has been addressed in detail elsewhere (e.g. Fassbinder et al. 2013), and because of the difficulty of categorizing the diversity of commercial and custom-built automated chamber methodologies. We further elaborate on the basic principles of static and dynamic chamber operation

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(pros/cons) on lines 99-116.

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 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 CO_2/H_2O measurement (∼4,000 USD). However, other analyzers could be readily employed with the chamber and manifold system described below.”

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