Manual Chamber Sampling Strategies to Help Account for Temporal Variability of Nitrous Oxide Emissions from Agricultural Cropping Systems

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Overview

• Choice of experimental design
  Improve ability to identify treatment effects

• Temporal variability
  Scales and Patterns

• Sampling Strategy
  Timing, Frequency, Logistics
The choice of experimental design can enhance or can weaken a study’s ability to detect treatment differences

• A number of studies address technical challenges of measuring GHG fluxes in the field

• Less attention towards statistical challenges of analyzing flux differences through time and across experimental treatments

• Very few studies investigate sampling strategies that maximize probability of detecting flux differences across treatments*

* Statistical power
Experimental Design: Key decisions

Key decisions in designing and analyzing field experiments include:

• How many plots per treatment
• Should plots be blocked
• If plots are blocked, how should they be delineated
• How many chambers within each plot
• How many samples per chamber closure to calculate flux rate

Statistical power can be greatly affected by the decisions made
Flux variability: Breakdown of sources

- Three experimental sites in Michigan: RCBD; 6 replications
- N$_2$O sampling: Manual Chambers (2-3 week sampling intervals)
- Sources of flux variability: Restricted Maximum Likelihood

Percent of total variance in N$_2$O flux rates attributed to different variability sources

Residual variance reflects variability in different chambers at different time points

Total variability of fluxes dominated by small-scale spatio-temporal variations at < 1 m$^2$ and measurement error sources

Kravchenko and Robertson 2014. In review
**Flux variability: Optimizing plot and chamber numbers**

<table>
<thead>
<tr>
<th>Combination</th>
<th>Power %</th>
</tr>
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<tbody>
<tr>
<td>Plots</td>
<td>Chambers per plot</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
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<td>3</td>
<td>6</td>
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Effect of the number of plots and chambers on statistical power:

Assumes 18 chambers per treatment and 50% difference between mean CO₂ flux rates of two treatments with α of 0.05.

The effect of chamber number per plot for comparing N₂O flux difference between two hypothetical treatments

Assumes six fold difference in N₂O flux between treatments with 6 replicated plots

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Kravchenko and Robertson 2014. In review
Flux variability: Suggestions for increased statistical power

- Increase the number of replicate plots per treatment over the number of chambers per plot
- Maximize the number of chambers per plot when number of replicate plots becomes limiting
- Maximize the number of gas samples per chamber to calculate flux rate
- Consider repeated measures analysis. Helps solve autocorrelation issues*
- Consult a statistician

* Measurements from same chamber are more similar to one another than measurements from other chambers and measurements closer in time more similar to one another than measurements separated by a longer time
Temporal Scales and Patterns

• What are the temporal scales of interest in cropping systems?
  \textit{Sub-daily, Growing season, Multi-year rotation}?

  \textbf{Can manual chambers address variability at relevant scales?}

• Appropriate sampling times and data interpolation requires knowledge of temporal emissions patterns at varying scales in the system of interest

  \textbf{Can we characterize these patterns?}
Temporal Patterns: Types

Pennock et al. (2006). Adapted from Brumme et al. (1999)
Temporal Patterns: Summary

Background:
• Low overall emissions - no obvious link to climate or other control
• Emissions pattern essentially random

Seasonal:
• Variable low-medium emissions with ‘gradual’ increases and decreases
• Emissions pattern linked to environmental conditions

Event + Seasonal:
• Seasonal pattern interrupted by several discrete pulses of N\textsubscript{2}O
• Pulses attributed to abrupt environmental change or management intervention
Temporal Patterns: Suggestions

• **Know your question**
  Are you testing differences among experimental treatments or attempting to construct an annual flux for GHG accounting purposes

• **Know your system!**
  Which pattern ‘operates’ at your location?

• **Until underlying pattern established it may be appropriate to sample according to event + seasonal type pattern***
  - Inclusion/exclusion of major flux events can lead to over/under estimation of the seasonal mean and total seasonal emissions
  - Few pulses with short duration reduce likelihood of capturing event

• **Couple background sampling (e.g., bi-weekly) with more frequent samplings (e.g., daily) during periods when emissions potentially higher**

* Depends on research goals – e.g., long-term research investigating inter-annual variability and / or comparisons of widely varying systems may require other approaches
Temporal Patterns: Event + seasonal sampling

Michigan: Corn-Soybean-Wheat rotation

$N_2O$ flux (g $N_2O$-N ha$^{-1}$ day$^{-1}$)

C-S-W, S-W-C, W-C-S

Millar et al. in preparation
Interpolation of the sporadic daily flux measurements made throughout the experimental period is required to calculate cumulative emissions

- Linear interpolation (i.e., the trapezoidal rule)
  - Simplest, most common and reproducible
  - Assumes observations are good estimate of average daily flux*  

- Estimating duration and magnitude of emissions on un-sampled days
  - Correlations between fluxes and controlling factor (e.g., Soil T and WFPS)
  - Intermediary between interpolation and more complex modeling

*Lack of information on duration and magnitude of event-based emissions and the diurnal pattern of emissions is a major limitation to temporal interpolation*

* May not be valid if pronounced diurnal pattern or for short duration emission events
Christensen et al. (1996): Vegetable crops in Denmark
- Multiple methods (chambers, FTIR, eddy covariance): 9 day comparison
- ≤18% variation in mean emissions between chamber and other methods

Smith and Dobbie (2001): Ryegrass in Scotland
- Manual (3-7 day) vs automated (8.0 hr): 7-48 day comparison
- 14% higher from automated. Not significant
- Improved correlation with manual sampling every day post N fertilization

- Automated (6.0 hr). 230 days (average daily N₂O emissions sub sampled)
- Sub-sampling every 4-8 days: within~ ±20% of ‘expected’ value

Evidence indicates manual chambers appropriate for long-term emissions estimates
Diurnal variability: No, Yes, Maybe, Sometimes?

- Flux values from manual sampling strategies typically assumed to be conservative and/or representative of average daily flux. ARE THEY?

*Important for estimates of longer-term cumulative emissions*

- Knowledge of the existence of diurnal patterns may improve understanding of origin of N$_2$O production under various conditions.

- Understanding of cause of transient fluxes may aid in identifying N$_2$O mitigation opportunities, and increase predictive accuracy of models.
“There is no short time during a 24-h period that is always satisfactory for assessing the amount of N\textsubscript{2}O evolved during that period”
Diurnal variability: What the literature tells us

Peak emissions coincidental with temperature:
Emissions originate in the upper soil

Peak emissions lag temperature:
Emissions from greater depth

Night time emissions peak:
Emissions from 20—30 cm and topsoil

Grazed fertilized grasslands

Smith et al. (1998)
Diurnal variability: Evidence from MI studies

Continuous Corn

Corn-Soybean

Corn-Soybean

Native Grass

GLBRC N₂O Automated: June 9-15, 2012
Diurnal variability: Suggestions

Know your system!

• Determine fluxes multiple times (≥ 3) in a day from varying treatments at various times of year (e.g., at times that ‘display’ background, seasonal and event type fluxes)

• Coincide with ancillary measurements (e.g., soil temperature and soil moisture [varying depths]) to generate relationships

• Based on results, identify appropriate time period for daily (one time) gas sampling that best represents average/conservative daily flux
Place chambers to capture potential variability of fluxes within single treatment due to management practice?

Characterize and assign micro-topographic landscapes within a treatment plot

For example, due to:

- Fertilizer banding
- Strip tillage
- Drip irrigation

1. Determine relative area (%) covered by specific topography
2. Calculate flux based on weighted average
Plantain in Puerto Rico

N application and timing (growth months)

- Drip irrigation: (1 - 4)
- Hand applied: (5 - 8)
- Foliar: (9 - 12)
Plantain: Chamber placement for spatial coverage

Top view

Cross section

3 x chamber per ‘micro-site’
(in row [close to plant], between plants, in alley)

3 x ‘micro-sites’ per treatment

2 x treatments (low N, high N)

18 (3 x 3 x 2) chambers
Field sampling: Logistical considerations

Trade-offs and inter-reliance between:

- Total number of chambers to sample from
- Time taken to sample each chamber
- Number of gas samples per closure (3, 4, more)
- Time interval between sampling rounds (e.g., 5, 10, 15 mins.)
- Sampling route
- Ancillary measurements
Field sampling: Suggestions

Recommendations:

• Prepare sample vials in order of collection in the field
• Place lids / vials alongside chambers before sampling
• Take chamber height/volume measurements before sampling
• Allow about 1 minute per sampling per vial
• Allow extra time for 1st sampling round (i.e., lid deployment)
• Allow extra time for sampling rounds with ancillary measurements (e.g., soil temp and water content)

About 15-20 chambers per sampler per sampling event
General Suggestions

- Choose experimental design and sampling strategy to maximize probability of detecting flux differences across treatments.
- Sample according to event + seasonal type pattern, unless experimental objectives dictate otherwise.
- Conduct sampling to determine diurnal variability of system at various times of year when emission patterns are likely to vary.
- Account for management practice within individual treatments by appropriate chamber placement.
- Do not sacrifice quality of sampling strategy for quantity of samples.
Thank You

Questions