Biogeochemical drivers of soil N₂O, CH₄, and CO₂ emissions from alfalfa using long-term continuous measurements

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Abstract

Agriculture is a significant source of carbon dioxide (CO₂) and methane (CH₄) and is the dominant source of anthropogenic nitrous oxide (N₂O) emissions. Changes in agricultural land management practices that reduce overall greenhouse gas (GHG) emissions have been suggested to help mitigate climate change, but a better understanding of the timing, magnitude, and drivers of GHG fluxes is needed. Alfalfa agroecosystems may be significant sources of N₂O given their ability to increase N inputs through symbiotic N₂ fixation and frequent irrigation events that create conditions for hot moments of N₂O production. However, few studies have explored long-term N₂O emissions and their associated drivers in alfalfa ecosystems. We collected over 108,000 CO₂, CH₄ and N₂O soil flux measurements over four years using cavity ring-down spectroscopy from a conventional flood-irrigated alfalfa field in California, USA. This ecosystem was a consistent source of N₂O (annual mean: 624.4 ± 27.8 mg N₂O m⁻² yr⁻¹, range: 263.6 ± 5.6 to 901.9 ± 74.5 mg N₂O m⁻² yr⁻¹) and a small net sink of CH₄ (annual mean: -53.5 ± 2.5 mg CH₄ m⁻² yr⁻¹, range: -78.2 ± 8.8 to -31.6 ± 2.5 mg CH₄ m⁻² yr⁻¹). Soil CO₂ fluxes averaged 4925.9 ± 13.5 g CO₂ m⁻² yr⁻¹ and were greater than other alfalfa ecosystem estimates, likely driven by elevated temperatures and plant productivity throughout the growing season. Hot moments of N₂O emissions represented only 0.2% to 1.1% of annual measurements but were 31.6% to 56.8% of the annual flux. We found that both the magnitude and the contribution of N₂O hot moments to annual emissions decreased over time. Normalized difference vegetation index (NDVI), soil temperature, moisture, and O₂ were all significantly correlated with soil CO₂, N₂O, and CH₄ fluxes, although associations varied across both soil depth and timescales. Our results suggest that flood-irrigated alfalfa is a significant source of agricultural N₂O emissions, and that plant productivity and soil moisture effects on O₂ availability may modulate the net GHG budget of alfalfa agroecosystems.
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### Introduction

- Alfalfa (*Medicago Sativa* L.) is the most common perennial forage legume worldwide and the largest crop by acreage in the Western U.S.$^1$
- Alfalfa is often thought of as a climate-friendly feedstock given its potential to increase soil C as a deep-rooting, perennial plant$^2$, and symbiotic nitrogen (N$_2$) fixer, decreasing inorganic fertilizer inputs.
- Long-term CO$_2$ and CH$_4$ studies suggest alfalfa can be a net C sink$^{3,4}$, but no continuous long-term N$_2$O studies exist.$^5$
- Alfalfa may be a significant N$_2$O source as enriched soil N and irrigation may stimulate hot moments of N$_2$O production.

### Methodology

- Jan 2016-Feb 2021: >108,000 CO$_2$, CH$_4$ and N$_2$O flux measurements from unfertilized alfalfa in California, USA with automated Eosense chambers and a Picarro greenhouse gas (GHG) analyzer.
- Apr 2018-Apr 2019: Weekly soil NO$_3$-, NH$_4$+ sampling.
- Sep 2018-Feb 2021: Continuous soil moisture, temperature, and oxygen (O$_2$) at 10, 30, and 50 cm.
- Fluxes up to 5.7 ± 0.8 kg N-N$_2$O ha$^{-1}$ yr$^{-1}$, and hot moments, only 1% of measurements, were 44% of total N$_2$O fluxes.

### Daily mean CO$_2$, CH$_4$, and N$_2$O fluxes

- Hot moments (fluxes > 4 SD) were 57% of N$_2$O fluxes, largely associated with flood irrigation.
- Strong seasonal trends in soil CO$_2$ fluxes closely followed air temperature and plant respiration.
- Alfalfa was a small net CH$_4$ sink with the largest sinks in 2020-21.

### Drivers of soil greenhouse gas emissions

- CO$_2$ coupled with temperature and normalized vegetation index (NDVI)
- N$_2$O coupled with soil O$_2$, moisture, and NDVI
- Significant wavelet coherence of all three GHGs with NDVI, temperature, moisture, and O$_2$, but varied across timescales.

### Table 1. Mean ± SE annual and hot moment (>4 SD) N$_2$O fluxes.

<table>
<thead>
<tr>
<th>Site Year</th>
<th>Annual mean (mg N$_2$O m$^{-2}$ d$^{-1}$)</th>
<th>Hot moment mean (mg N$_2$O m$^{-2}$ d$^{-1}$)</th>
<th>Hot moment % of flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (2017-18)</td>
<td>611 ± 68</td>
<td>496 ± 67</td>
<td>+56.8%</td>
</tr>
<tr>
<td>2 (2018-19)</td>
<td>902 ± 74</td>
<td>457 ± 43</td>
<td>+55.3%</td>
</tr>
<tr>
<td>3 (2019-20)</td>
<td>777 ± 52</td>
<td>363 ± 46</td>
<td>+37.5%</td>
</tr>
<tr>
<td>4 (2020-21)</td>
<td>264 ± 6</td>
<td>20 ± 1</td>
<td>+31.6%</td>
</tr>
<tr>
<td>All years</td>
<td>624 ± 28</td>
<td>401 ± 27</td>
<td>+44.4%</td>
</tr>
</tbody>
</table>

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### References


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