Biogeochemical drivers of soil N_2O, CH_4, and CO_2 emissions from alfalfa using long-term continuous measurements

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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_2O studies exist[4-5].
- Alfalfa may be a significant N_2O source as enriched soil N and irrigation may stimulate hot moments of N_2O production.

Methodology

- **Jan 2016-Feb 2021:** >108,000 CO_2, CH_4 and N_2O 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_2O ha^{-1} yr^{-1}, and hot moments, only 1% of measurements, were 44% of total N_2O fluxes**

Site Year	Annual mean (mg N_2O m^{-2} y^{-1})	Hot moment mean (mg N_2O m^{-2} d^{-1})	Hot moment % of flux
1 (2017-18)	611 ± 68	496 ± 67	+56.8%
2 (2018-19)	902 ± 74	457 ± 43	+55.3%
3 (2019-20)	777 ± 52	363 ± 46	+37.5%
4 (2020-21)	264 ± 6	20 ± 1	+31.6%
All years	624 ± 28	401 ± 27	+44.4%

Table 1. Mean ± SE annual and hot moment (>4 SD) N_2O fluxes.

Daily mean CO_2, CH_4, and N_2O fluxes

- **Hot moments (fluxes > 4 SD) were 57% of N_2O 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.**

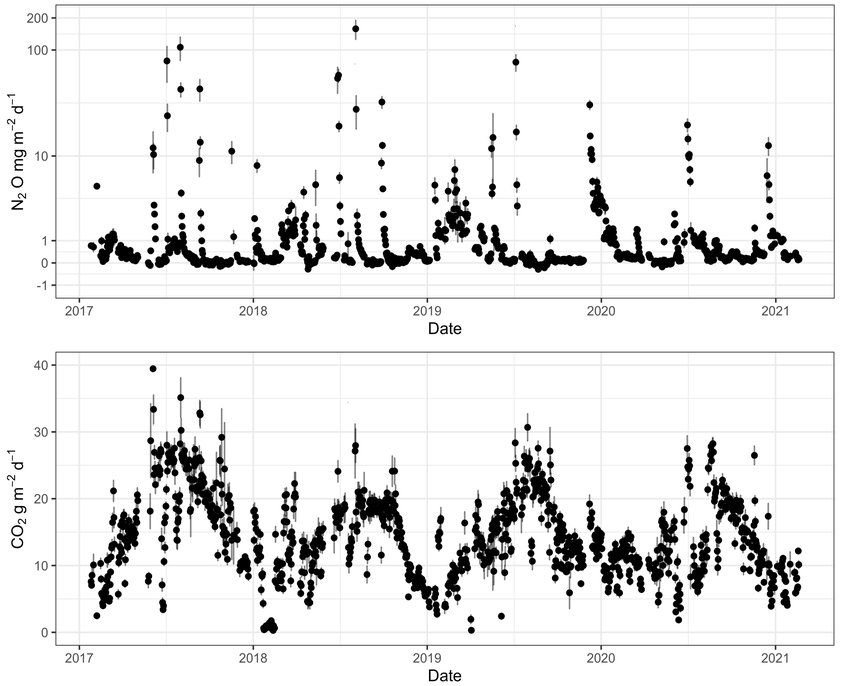
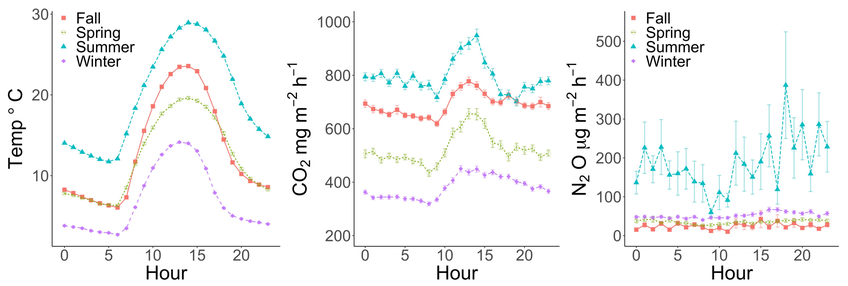


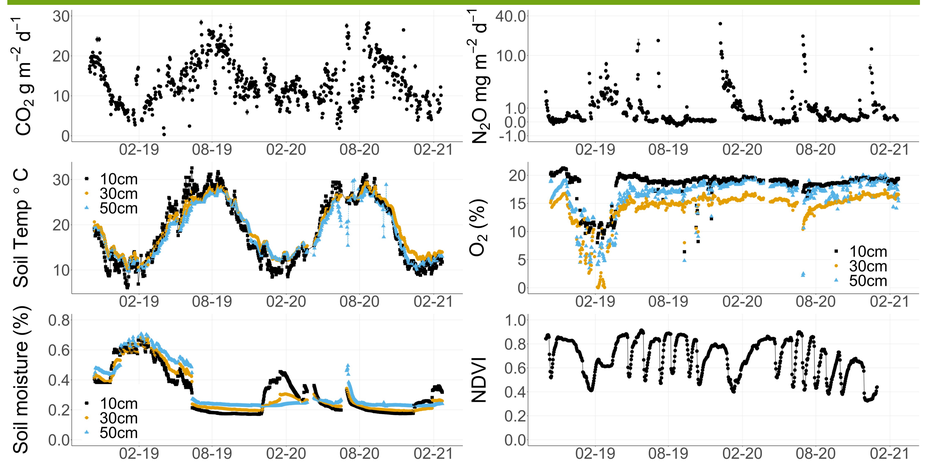
Fig. 1 Daily mean fluxes (± standard error) for N_2O and CO_2. Black circles represent daily mean flux measurements.

Diels trends in soil greenhouse gas emissions

- **Diel CO_2 fluxes followed similar trends to temperature**
- **N_2O fluxes significantly higher in summer, lagged temperature**



Drivers of soil greenhouse gas emissions



- **CO_2 coupled with temperature and normalized vegetation index (NDVI)**
- **N_2O 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.**

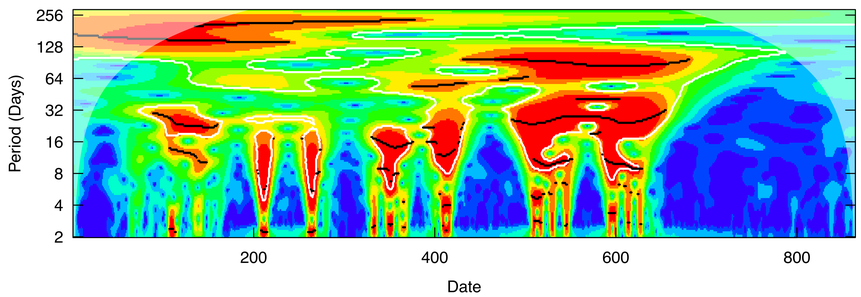


Fig. 4 Example wavelet coherence of N_2O and O_2 at 10 cm. Red = significant.

Conclusions

- **Alfalfa is a significant N_2O source (up to 5.7 ± 0.8 kg N-N_2O ha^{-1} yr^{-1}), and hot moments are up to 57% of annual N_2O flux.**
- **N_2O fluxes offset net ecosystem CO_2e sink by 10-20% even without N inputs**
- **Significant coherence with NDVI, temperature, moisture, and O_2 suggest plant productivity and soil O_2 modulate GHG budgets.**

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References

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