Importance of Soil O₂

Aerobic vs. Anaerobic

Burgin et al. 2007 *Frontiers in Ecology and the Env.*

<table>
<thead>
<tr>
<th>GHG</th>
<th>Aerobic</th>
<th>Variable</th>
<th>Anaerobic</th>
<th>Processes</th>
</tr>
</thead>
</table>
| CH₄  | +       | +/−,?    | −         | CO₂ + 4 H₂ \(\rightarrow\) CH₄ + 2H₂O  
CH₄ + O₂ \(\rightarrow\) CO₂ + H₂O |
| CO₂  | −       | +,?      | +         | C₆H₁₂O₆ + O₂ \(\rightarrow\) CO₂ + H₂O  
C₆H₁₂O₆ + aTEAs \(\rightarrow\) CO₂ + H₂O |
| N₂O  | −+/+    | −,?      | +         | NO₃ → NO₂ \(→\) NO \(\rightarrow\) N₂O \(\rightarrow\) N₂  
NH₄ + O₂ \(\rightarrow\) N₂O \(\rightarrow\) NO₂ \(\rightarrow\) NO \(\rightarrow\) NO₃ |
Soil $O_2$ - rise faster than fall

Burgin and Groffman 2012 JGRB
$O_2$ across Aquatic-Terrestrial Interfaces

Riparian Areas

- Perennially
- Regularly
- Periodically
- Infrequently

Frequency

- Low soil $O_2$
- High soil $O_2$

Figure from Bettez and Groffman 2012 – ES&T
Wetland Restoration

1880’s

2011

2012
Soil Sensor Network

- 24 Apogee soil O$_2$ sensors at 10 cm depth
- 28 soil moisture, temperature, and conductivity at 10, 30, 50, and 80 cm
- 12 Water table height
- Weather station: wind, temperature, PAR

- Taking weekly GHG flux since 2010
Typical soil O2 time series

Raw
Typical soil O2 time series

Raw

Noise Corrected
Typical soil O2 time series

- Raw
- Noise Corrected
- Drift Corrected
Diversity of soil $O_2$ conditions

Most Anoxic

Most Oxic
3-repeatable patterns only observed w/ near-continuous monitoring
1. Diurnal fluctuation – daily pulse
2. Lag in O₂ depletion
3. Rapid reaeration – “big gulp”
1. Diurnal variation in soil $O_2$
1. Diurnal variation in soil $O_2$
1. Diurnal variation in soil $O_2$

Daily max $O_2$ lags behind daily min air temp by 2 hours and 1.5 hours behind daily min soil temp.
- Temperature response not temperature artifact.
- PAR also important, max PAR lags max $O_2$ by 6.5 hours.
3-repeatable patterns only observed w/ near-continuous monitoring

1. Diurnal fluctuation – daily pulse
2. Lag in O₂ depletion
3. Rapid reaeration – “big gulp”
2. Temperature control on soil $O_2$ depletion in saturated soils

$R^2 = 0.43 \quad p<0.0001$

$y = -3.47 + 0.057x \degree C$

$Q_{10} = 1.77$
3-repeatable patterns only observed w/ near-continuous monitoring
1. Diurnal fluctuation
2. Lag in $O_2$ depletion
3. Rapid reaeration – “big gulp”
3. Big gulps occur during soil drainage

Saturated soil

Macropore Drainage
Big gulps consistently occur within narrow threshold of soil drainage

75% of variation among sensors
25% of variation within sensors
n=1813 events
Common diffusion soil $O_2$ models fail to predict hysteresis between soil moisture and soil $O_2$. 

[Diagram showing scatter plot with arrows indicating hysteresis and a diffusion model line.]
Do big gulps correspond to big burbs?

Jarecke, Loecke, & Burgin  SBB 2016
Smyth et al. SBB 2019
O_2 sensor best for CH_4 flux

Smyth et al. SBB 2019
O$_2$ sensor not best for N$_2$O flux

Smyth et al. SBB 2019
In-situ soil $O_2$ monitoring

- Monitoring reveals surprising dynamics not predicted in common BGC models (e.g., DNDC and DAMM)
- Repeatable patterns are related to duration of soil saturation, soil temperature, and soil drainage
- Big Gulps = Big Burbs?
  - General indicator of soil-atmosphere exchange
- Plan for sensor drift
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Soil O2 data - Filtering

• Sensor or Calibration Drift
  – Compare expected to observed
  – Drift correction

• Electrical Noise
  – Insure not related environment
  – Replace as missing
Remove sensor from soil and place in calibration condition
Allow stabilization
Subtract final stable from 20.9%
Apply drift correction
NEAR SURFACE SOIL OXYGEN DYNAMICS: PATTERNS FROM SIX YEARS OF HIGH FREQUENCY MONITORING

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Soil oxygen (O$_2$) is a fundamental control on terrestrial biogeochemical cycles including processes producing and consuming greenhouse gases (GHG), yet it is rarely measured. Instead, soil O$_2$ is assumed to be proportional to soil moisture and physical soil properties. For example, soil O$_2$ is often inferred from a 25-year old steady-state diffusion model; however, few data exist to test this model in stochastic systems. The variability of soil O$_2$ may be particularly important to GHG emissions from aquatic-terrestrial interface zones because of the convergence of variable hydrology and rapid biogeochemical processing. Our objective is to gain a better understanding of soil O$_2$ variation and its role in controlling GHG emissions across aquatic-terrestrial interface zones. Specifically, we hypothesize that in aquatic-terrestrial interface ecosystems, soil moisture predicts O$_2$ concentration under stable conditions, but under dynamic conditions (e.g., water table fluctuations or precipitation) heterogeneous distributions of water-filled soil pore space complicate this prediction. Furthermore, we hypothesize that GHG emissions will correspond to variation in soil O$_2$.

Twenty-four near-continuous (30-minute frequency) soil O$_2$ and moisture sensors were monitored for more than six years. The sensors were installed at 10 cm of depth across an aquatic-terrestrial interface of a constructed wetland in April 2012 and removed in July 2018. Diurnal, precipitation and drainage events, seasonal, and longer-term patterns were in soil O$_2$ observed. Drought conditions (2012) resulted in minimal soil O$_2$ variation; however, a diurnal pattern of lower soil O$_2$ during the day was observed. When precipitation increases within and among sensor soil O$_2$ variation increases. The relationship between soil moisture and soil O$_2$ was non-linear during periods of soil drainage and precipitation. Commonly, a rapid (change of 10% over <24 hours) increase in soil O$_2$ occurred during soil drainage near a common threshold. As soil moisture increased due to precipitation, soil O$_2$ decreased slower than predicted by simple diffusion models. Soil O$_2$ was an important predictor of weekly methane and nitrous oxide emissions correspond to variation in soil O$_2$. These soil O$_2$ data will be useful for understanding multiple soil biogeochemical functions.
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