Soil Respiration Tests as Predictors of Nitrogen Mineralization Potential

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In this talk

• Study objectives
• Background on soil N tests
• Rationale for soil CO$_2$ as proxy for N min
• Study and experimental design
• Results
  – Chemical indices
  – Biological indices
  – Location effects
• Test evaluation and feasibility
• Conclusion
Project Objectives

• 1. Evaluate if the flush of CO$_2$ from soils can predict growing season soil N mineralization across a range of soils that vary in fertilizer N requirements, soil amendments (crop residues and manures and composts), organic matter contents and other agronomic practices.

• 2. Develop correlations to other tests such as total soil N, total soil organic matter, crop N uptake and pre-crop nitrate levels to predict soil N mineralization potential with the main goal of reassessing fertilizer N applications for important California crops.

• 3. Evaluate the cost-effectiveness of implementing biologically based soil assays and procedures in commercial soil test labs.
Nitrogen Mineralization

- Nitrogen mineralization is the term for the breakdown of soil organic matter into plant-available forms, such as ammonium ($\text{NH}_4^+$) and nitrate ($\text{NO}_3^-$).
- This process occurs on both managed and unmanaged soils, providing most of the N that plants need, although it is often the biggest nutrient limitation in unmanaged systems.
- In managed systems, this process is often unaccounted for when making fertilizer recommendations.

<table>
<thead>
<tr>
<th>Crop N Requirements vs. Soil N Supplying Capacity</th>
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</thead>
<tbody>
<tr>
<td><strong>Crop N Requirements</strong></td>
</tr>
<tr>
<td>178 lbs/ac N in grain</td>
</tr>
<tr>
<td>72 lbs/ac N in leaves</td>
</tr>
<tr>
<td><strong>Total Crop N uptake</strong></td>
</tr>
<tr>
<td>250 lbs/ac N</td>
</tr>
</tbody>
</table>
Nitrogen Uptake Synchrony

- One reason that the contribution of soil to plant-available N is neglected is that the timing and amount released is difficult to predict (2 of the 4 R’s).
- Soils higher in organic matter will have a higher ability to supply N for plant uptake.
- The rate of mineralization peaks in a different window than crop N uptake, so the difference is usually accounted for by N fertilization.
Estimating Mineralizable N

- Most lab tests are a chemical extraction to tell you what is available to be mineralized and become plant available.
- This decomposition is a process largely controlled by the soil microbial community, yet many lab tests neglect to measure the soil biological components.
- Similar to having a dinner party and only knowing how much food you have, but not how many people are showing up, or how much they can eat.
Other Soil N Tests

- Preplant soil nitrate
- NaHCO$_3$-UV (Fox & Piekielek, 1978)
- Pre-sidedress soil nitrate (Magdoff et al., 1984 & Magdoff, 1991)
- Hot KCl extractable NH$_4$-N (Gianello & Bremner, 1986)
- Hydrolyzable N (Gianello & Bremner, 1986)
- Phosphate-borate distillable N (Gianello & Bremner, 1986)
- Cold KCl extractable NO$_3$-N (Mulvaney, 1996)
- Direct diffusion method (Khan et al., 2000 & 2001)
- Calcium hypochlorite (Picone et al., 2002)
- Sodium-Hydroxide distillable N (Sharifi et al., 2007)
Integrating Soil Biology: Respiration

- The measurement of mineralized C (CO$_2$) could simultaneously allow for differences in microbial community size and activity, allowing for a relationship to be established with net N mineralization.
Integrating Soil Biology: Respiration

- The relationship varies across climatic regions

![Graph showing the relationship between Net N mineralization and C mineralization in different climatic regions: Alberta/BC, Maine, Texas, Georgia.](image)

Franzluebbers et al., 2000
• Correlation found between 1 day CO\textsubscript{2} and 28 day net N mineralization on Texas soils amended with composted dairy manure
• A standardized method would allow for rapid estimation of N mineralization in soil test labs.

Haney, Brinton, & Evans, 2008
Study soils

- Four agricultural regions (Yolo, San Joaquin, Salinas and Fresno/Kern counties), representing a climatic gradient
  - Climatic gradient measured as aridity index (precipitation/average annual temperature)
  - Increasing aridity as we move south
  - Variety of crops included: corn, processing tomatoes, sorghum, almonds, lettuce, & spinach
- Management categorized by presence of winter cover crop immediately prior to growing season
Parameters Included

• Chemical Indices
  – Net N Mineralization measured in lab ($\text{NMIN}_t$)
  • Change in inorganic N ($\text{NO}_3^- + \text{NH}_4^+$) at time($t$) = 14, 28, 56 & 105 days
  – C and N fractions assessed using three methods, which were to be assessed against one another

• Biological Indices
  – Cumulative Respiration (CMIN)
    • measured at 6, 24, and 72 Hours after rewetting
  – Permanganate-oxidizeable carbon (POXC): assessed as “biologically-active” carbon
Estimating Potentially Mineralizable N

- Anaerobic Incubation (Waring and Bremner, 1964): soils are water-logged for 7 days at 40°C
  - Inconsistent correlations between lab and field measures in agricultural soils (better in forest)
- Aerobic Incubation (Stanford & Smith, 1972): air-dried and then rewetted soils measured and fit to first-order kinetics
  \[ N_t = N_0 \times (1-e^{-kt}) \]

- Many other tests have been developed, but none have been successful over a broad range of sites
Results: N Mineralization

- Net N mineralization increased throughout the incubation; most values within the following ranges
  - $\text{NMIN}_{28}: 43.5-75.3$ lbs N/ac
  - $\text{NMIN}_{56}: 44.5-72.4$ lbs N/ac
  - $\text{NMIN}_{105}: 52.6-88.2$ lbs N/ac
- Significant management effects at each date, with cover cropped fields having higher N mineralization than non-cover cropped
- Release dynamics are similar between managements
Results: Chemical Indices

- Total N showed the best overall relationships, followed by WEON and then DON.
- N fractions were better than their corresponding C fraction, although for most C fractions, there was a significant relationship with N mineralization.
- A maximum of 31.9% of variation in N mineralization was explained by a single chemical indicator.

<table>
<thead>
<tr>
<th></th>
<th>NMIN$_{28}$</th>
<th>NMIN$_{56}$</th>
<th>NMIN$_{105}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total C</strong></td>
<td>0.351**</td>
<td>0.433**</td>
<td>0.280*</td>
</tr>
<tr>
<td><strong>Total N</strong></td>
<td>0.432**</td>
<td>0.565***</td>
<td>0.349**</td>
</tr>
<tr>
<td><strong>DOC</strong></td>
<td>0.191$^{NS}$</td>
<td>0.234$^{NS}$</td>
<td>0.291*</td>
</tr>
<tr>
<td><strong>DON</strong></td>
<td>0.322*</td>
<td>0.343**</td>
<td>0.308*</td>
</tr>
<tr>
<td><strong>WEOC</strong></td>
<td>0.269*</td>
<td>0.286*</td>
<td>0.344**</td>
</tr>
<tr>
<td><strong>WEON</strong></td>
<td>0.389**</td>
<td>0.332**</td>
<td>0.369**</td>
</tr>
</tbody>
</table>

*,**,*** refers to significance at p<0.05, p<0.01, and p<0.001, respectively. 
NS = not significant.
Results: Biological Indices

- Biological indicators were generally less accurate than chemical indices.
- 72-Hour respiration ($\text{CMIN}_{0-72}$) had the strongest overall relationships.
- A maximum of 13.1% of the variation in N mineralization could be explained using a biological indicator alone.

<table>
<thead>
<tr>
<th></th>
<th>CMIN$_{0-6}$</th>
<th>CMIN$_{0-24}$</th>
<th>CMIN$_{0-72}$</th>
<th>POXC</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMIN$_{28}$</td>
<td>0.292**</td>
<td>0.362***</td>
<td>0.311***</td>
<td>0.193*</td>
</tr>
<tr>
<td>NMIN$_{56}$</td>
<td>0.263**</td>
<td>0.211**</td>
<td>0.294**</td>
<td>0.036$^{NS}$</td>
</tr>
<tr>
<td>NMIN$_{105}$</td>
<td>0.210**</td>
<td>0.324***</td>
<td>0.297**</td>
<td>0.134$^{NS}$</td>
</tr>
</tbody>
</table>

*, **, *** refers to significance at $p<0.05$, $p<0.01$, and $p<0.001$, respectively. NS = not significant.
Results: Biological and Chemical Indices

- Table shows NRMSE values, an indicator of error where higher values show greater error, so lower values are a better indicator.
- Management had a strong effect on accuracy of predictions: cover cropped fields were much more accurate than the non-cover cropped fields (or when all fields were pooled together).
- Best biological indicator was 72-hour respiration, regardless of management.
- Best chemical indicator was water-extractable C/N across all fields, but in cover cropped fields, it was DOC/N.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>All Fields</th>
<th>Cover Crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24-Hr Respiration</td>
<td>0.350\textsuperscript{ab}</td>
<td>0.254\textsuperscript{a}</td>
</tr>
<tr>
<td>72-Hr Respiration</td>
<td>0.340\textsuperscript{b}</td>
<td>0.233\textsuperscript{b}</td>
</tr>
<tr>
<td>POXC</td>
<td>0.357\textsuperscript{a}</td>
<td>0.243\textsuperscript{ab}</td>
</tr>
<tr>
<td>Chemical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total C/N</td>
<td>0.364\textsuperscript{a}</td>
<td>0.300\textsuperscript{a}</td>
</tr>
<tr>
<td>DOC/N</td>
<td>0.357\textsuperscript{a}</td>
<td>0.169\textsuperscript{c}</td>
</tr>
<tr>
<td>WEOC/N</td>
<td>0.326\textsuperscript{b}</td>
<td>0.262\textsuperscript{b}</td>
</tr>
</tbody>
</table>

For each column, letters indicate significant differences (p<0.05) within a management and index type.
### Results: Location Effects

- **Biological indicators:** all approximately equal within each management strategy in each location, so differences may be due to climatic variables.
- **Chemical indicators:** DOC/N was still the best indicator across all locations and managements, although it wasn’t different than total C/N in Yolo County (least arid).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fresno/Kern Counties</th>
<th>Yolo County</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Fields</td>
<td>Cover Crops</td>
</tr>
<tr>
<td>Biological</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24-Hr Respiration</td>
<td>0.258( ^a )</td>
<td>0.166( ^a )</td>
</tr>
<tr>
<td>72-Hr Respiration</td>
<td>0.254( ^a )</td>
<td>0.140( ^a )</td>
</tr>
<tr>
<td>POXC</td>
<td>0.271( ^a )</td>
<td>0.148( ^a )</td>
</tr>
<tr>
<td>Chemical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total C/N</td>
<td>0.316( ^a )</td>
<td>0.180( ^a )</td>
</tr>
<tr>
<td>DOC/N</td>
<td>0.169( ^b )</td>
<td>0.086( ^b )</td>
</tr>
<tr>
<td>WEOC/N</td>
<td>0.299( ^a )</td>
<td>0.188( ^a )</td>
</tr>
</tbody>
</table>

For each column, letters indicate significant differences (p<0.05) within a management, location, and index type.
Test Evaluation

- **Management:** prediction of N mineralization is unreliable on California soils that have not had the recent incorporation of cover crops

- **Best Predictor variables:** 72-hour respiration, combined with DOC/N allowed for most accurate predictions ($R^2=0.18-0.53$) when looking across all growing regions

- **Location:** all biological indicators were similarly accurate within a climatic zone, but DOC/N was still best chemical predictor
  - Increased accuracy within each growing region, when using cover crops
    - Yolo County: $R^2=0.23-0.46$
    - Fresno/Kern Counties: $R^2=0.32-0.89$

- Generally low correlations show high degree of uncertainty in predictions, although further regional calibrations may improve accuracy
Feasibility

• Cost Analysis
  – For use with cover crops only:
    • assumed price of N = $0.82/lb N in California
    • Net Mineralization at 28 days: $39.69 - $79.95/ac in potential savings
    • Net N mineralization at 56 days: $40.43 - $75.60/ac in potential savings
    • Net Mineralization at 105 days: $46.17-91.43 /ac in potential savings
  – Cost of lab analysis: $50-75 per sample, but a sample can be used to represent several acres
  – Taking multiple samples from across a field will increase accuracy
  – Does not account for potential yield loss due to low N- will vary by crop
• Sampling: samples should be taken as close to fertilizer application as possible for increased accuracy of estimation
• Lab Analysis: proposed analyses are moderately time/labor intensive, which could limit their feasibility in a lab setting
Conclusions

• Utilizing soil respiration is ineffective when utilized as the sole estimator of net N mineralization in a wide range of California agricultural soils
• Prediction is only valid on fields with recent cover crop incorporations
• Dissolved organic carbon and nitrogen (DOC/DON) serve as useful predictors across growing regions
• Regional calibrations of predictions would allow for much greater certainty
• The expense of the combined respiration and chemical tests can be offset by savings in N fertilizer
  – Potential yield losses due to insufficient N not accounted for
• Combining these indicators may ultimately be limited by time and labor constraints at both sampling and processing of soil samples
Acknowledgements

• This project was funded (in part) by a grant from the California Department of Food and Agriculture’s Fertilizer Research and Education Program (FREP) and the Fertilizer Inspection Advisory Board.

• Growers that have collaborated on this study

• Professor William R. Horwath & Lab mates

• J. G. Boswell Endowed Chair in Soil Science