Soil Respiration Tests as Predictors of Nitrogen Mineralization Potential

Jordon Wade, Martin Burger,
& William R. Horwath

Dept. of Land, Air, & Water Resources
University of California, Davis

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

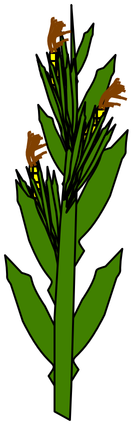
- 1. Evaluate if the flush of CO_2 from soils can predict growing season soil N mineralization across a range of soils that vary in fertilizer N requirements, soil amendments (crop residues and manures and composts), organic matter contents and other agronomic practices.
- 2. Develop correlations to 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 (NH_4^+) and nitrate (NO_3^-)
- This process occurs on both managed and unmanaged soils, providing most of the N that plants need, although is often the biggest nutrient limitation in unmanaged systems
- In managed systems, this process is often unaccounted for when making fertilizer recommendations

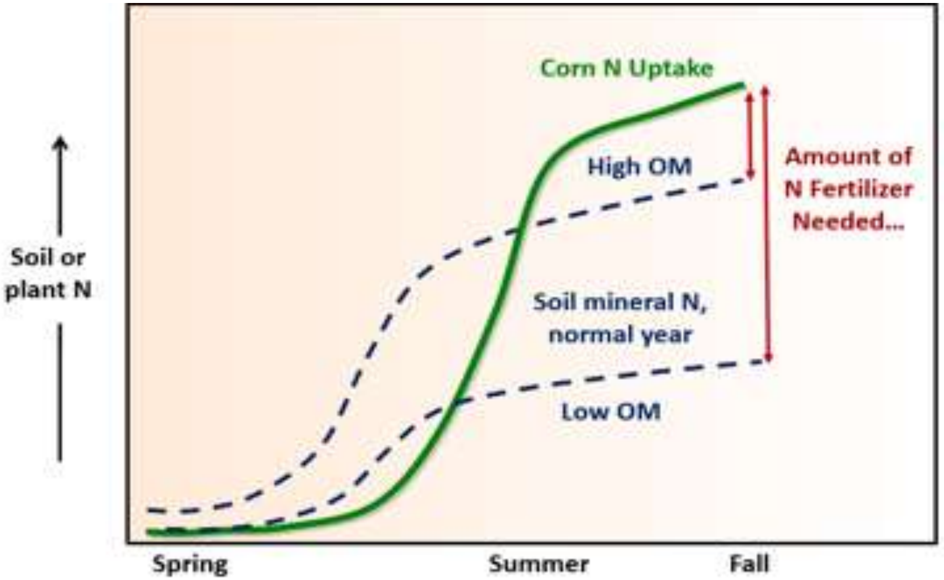
Crop N Requirements vs. Soil N Supplying Capacity

Crop N Requirements	Soil N Supplying Capacity
178 lbs/ac N in grain	~5400 lbs/ac N in top 30cm of soil profile
72 lbs/ac N in leaves	2-5% mineralizes annually
Total Crop N uptake 250 lbs/ac N	**Total Soil N Supply 110-270 lbs/ac N per year**



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



From Cornell Field Crops newsletter

Estimating Mineralizable N

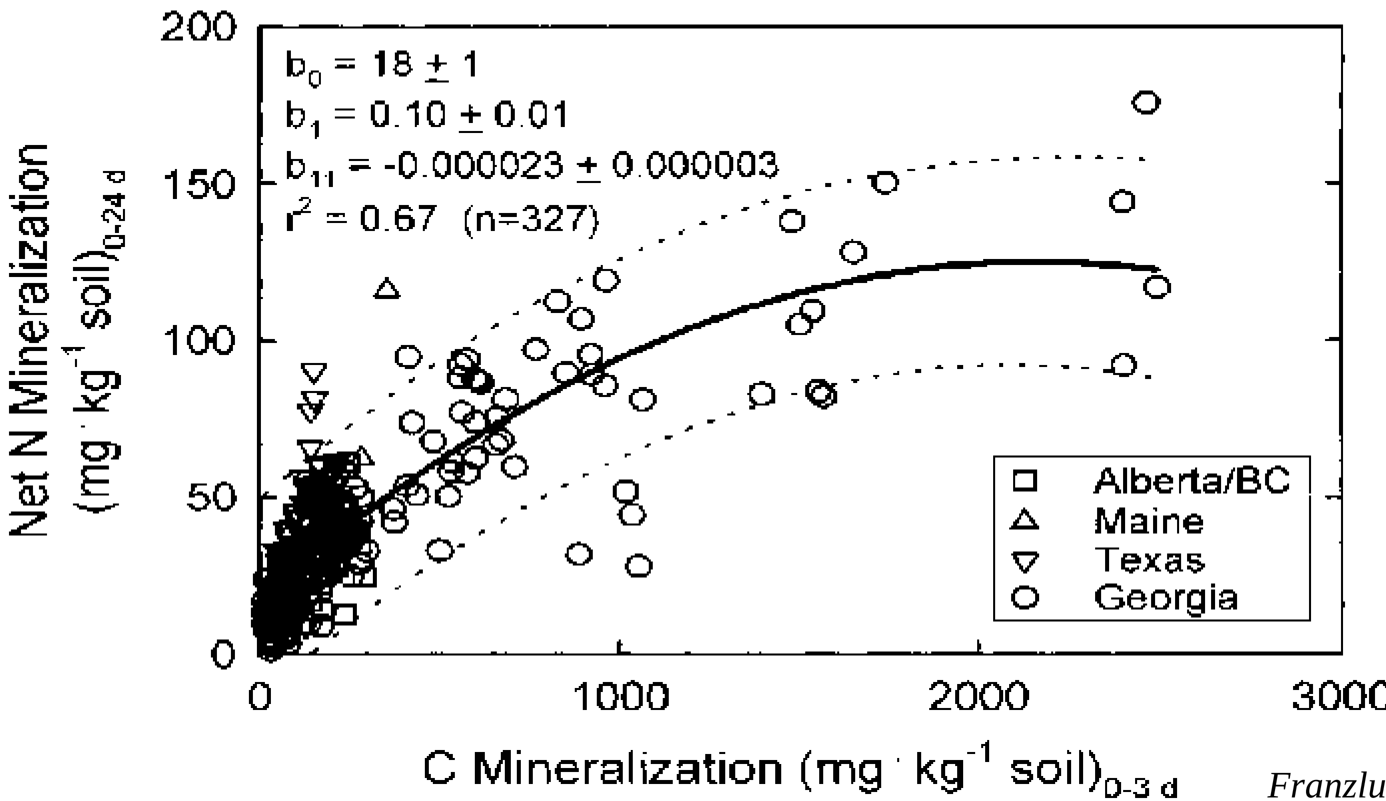
- Most lab tests are a chemical extraction to tell you what is available to be mineralized and become plant available
- This decomposition is a process largely controlled by the soil microbial community, yet many lab tests neglect to measure the soil biological components
- Similar to having a dinner 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

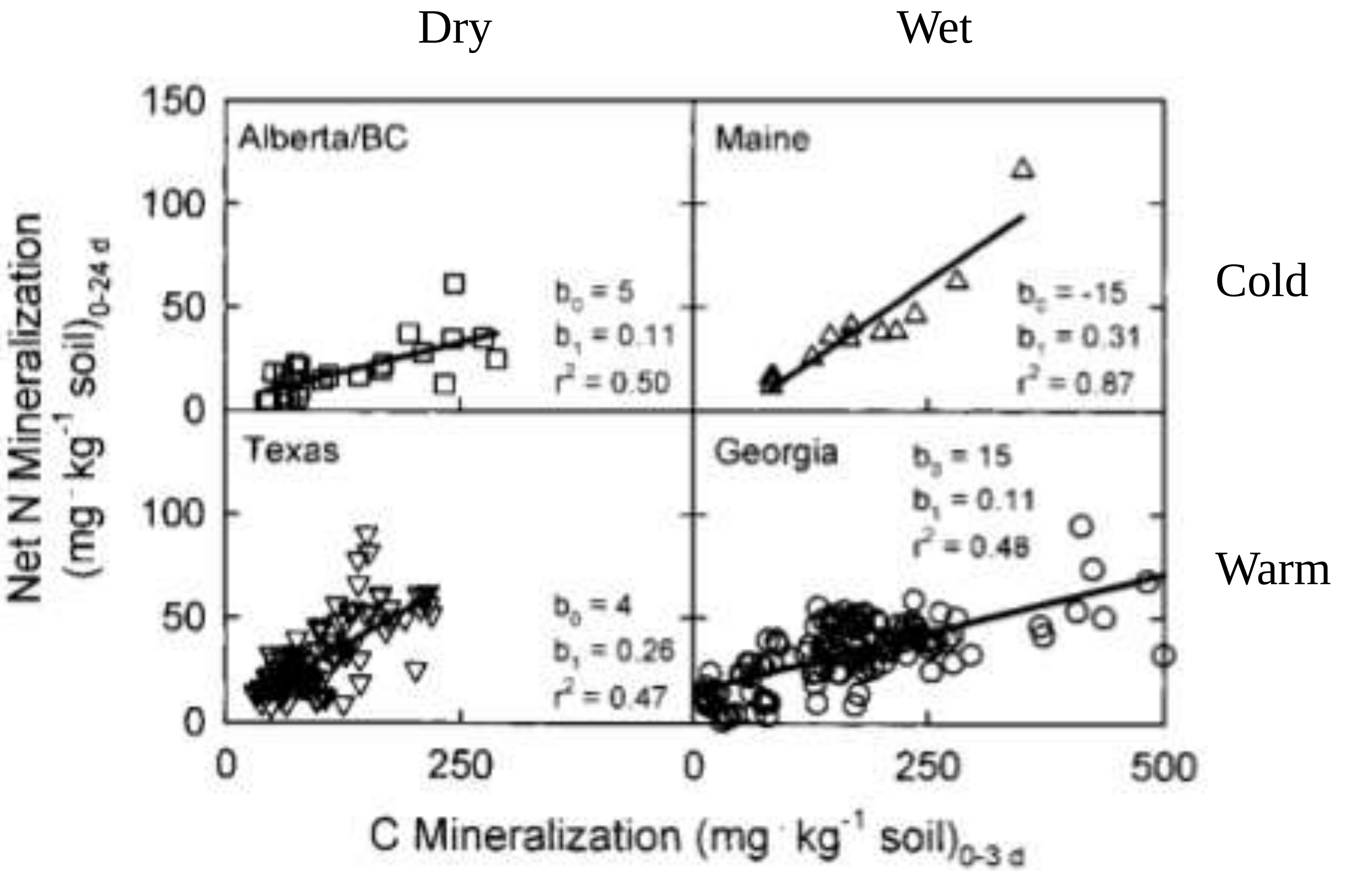
- The measurement of mineralized C (CO_2) could simultaneously allow for differences in microbial community size and activity, allowing for a relationship to be established with net N mineralization



Franzluebbers et al., 2000

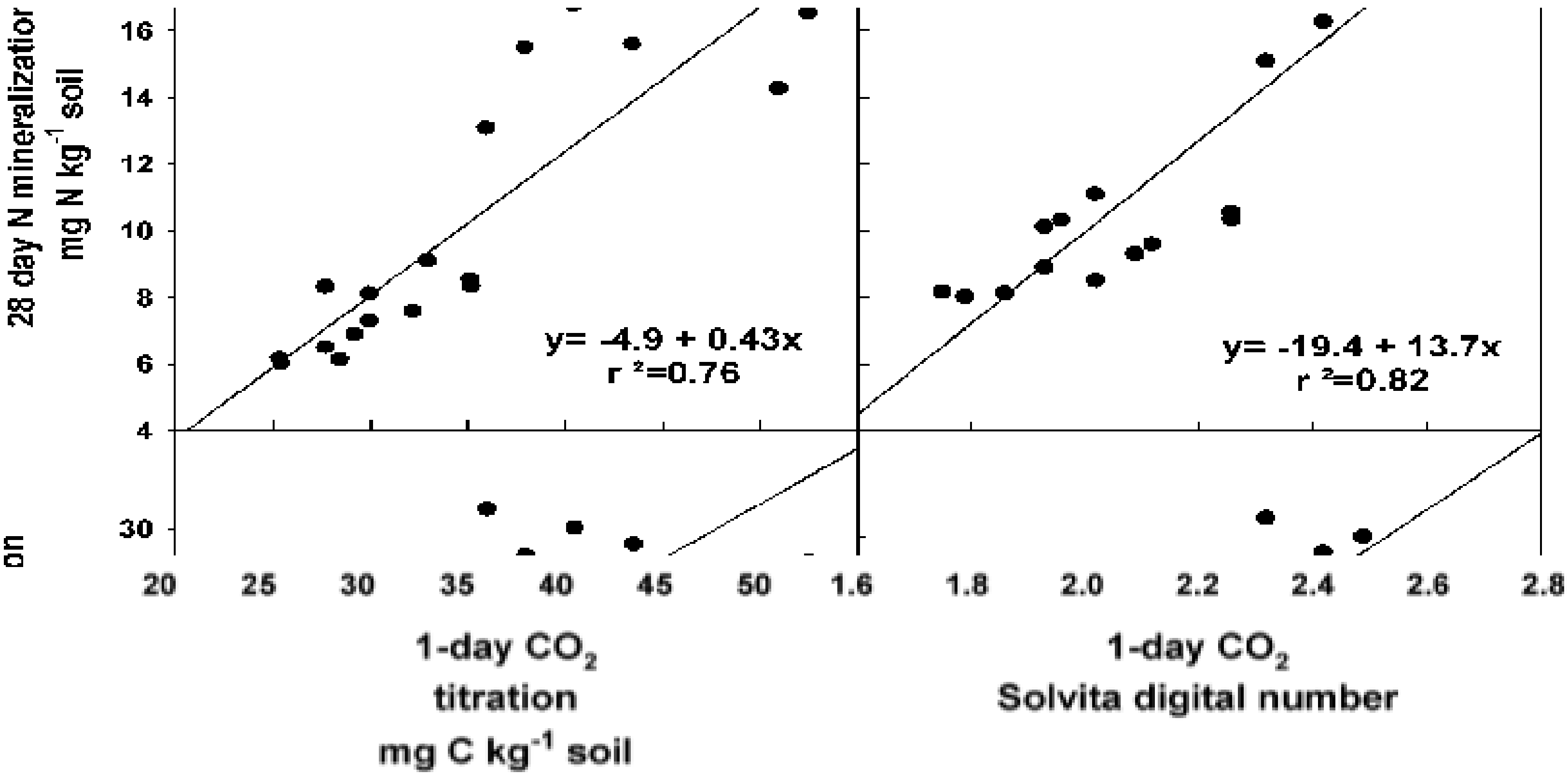
Integrating Soil Biology: Respiration

- The relationship varies across climatic regions



Franzluebbers et al., 2000

Coupling C and N Mineralization



Haney, Brinton, & Evans, 2008

- Correlation found between 1 day CO_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.

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

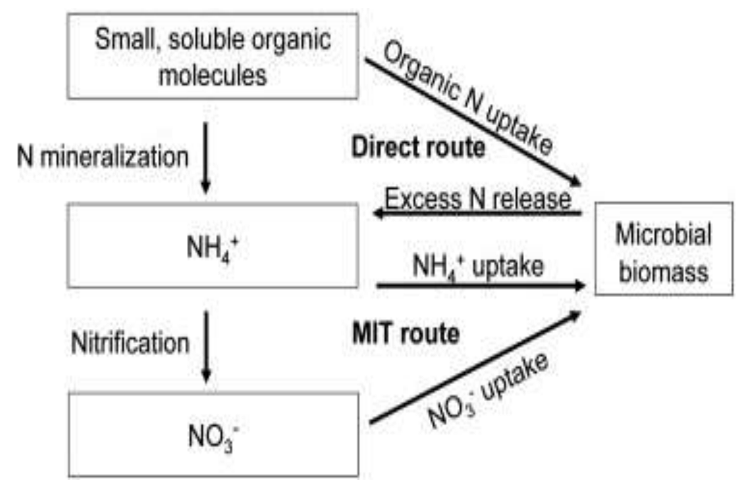
Parameters Included

- Chemical Indices
  - Net N Mineralization measured in lab ($NMIN_t$)
    - Change in inorganic N (NO_3^- + 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

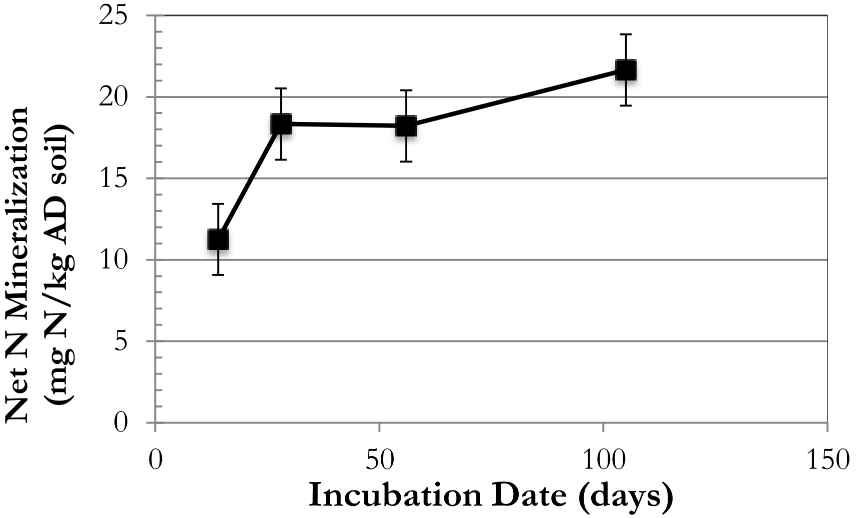
$$N_t = N_0 * (1 - e^{-kt})$$

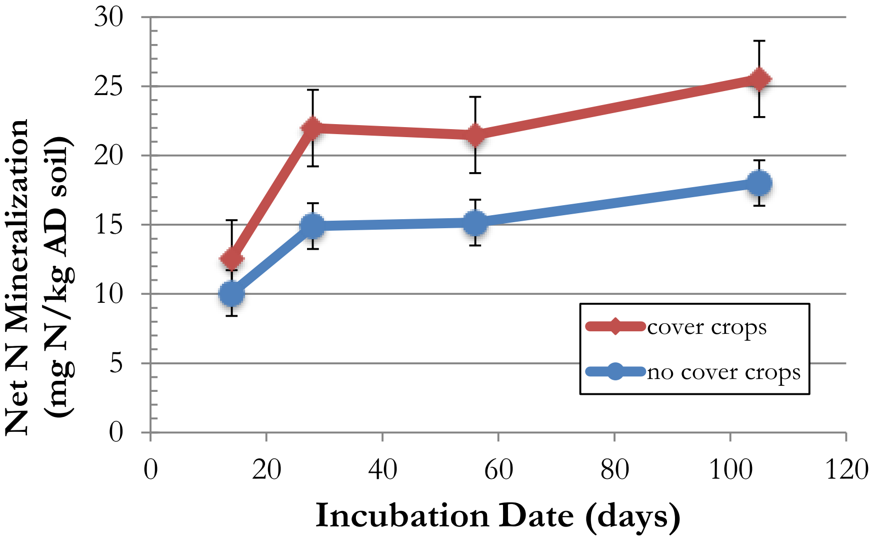


- Many other tests have been developed, but none have been successful over a broad range of sites

Results: N Mineralization

- Net N mineralization increased throughout the incubation; most values within the following ranges
  - $NMIN_{28}$: 43.5-75.3 lbs N/ac
  - $NMIN_{56}$: 44.5-72.4 lbs N/ac
  - $NMIN_{105}$: 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

	$NMIN_{28}$	$NMIN_{56}$	$NMIN_{105}$
Total C	0.351**	0.433**	0.280*
Total N	0.432**	0.565***	0.349**
DOC	0.191^{NS}	0.234^{NS}	0.291*
DON	0.322*	0.343**	0.308*
WEOC	0.269*	0.286*	0.344**
WEON	0.389**	0.332**	0.369**

*, **, *** 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 ($CMIN_{0-72}$) had the strongest overall relationships
- A maximum of 13.1% of the variation in N mineralization could be explained using a biological indicator alone

	$CMIN_{0-6}$	$CMIN_{0-24}$	$CMIN_{0-72}$	POXC
$NMIN_{28}$	0.292^{**}	0.362^{***}	0.311^{***}	0.193^{*}
$NMIN_{56}$	0.263^{**}	0.211^{**}	0.294^{**}	0.036^{NS}
$NMIN_{105}$	0.210^{**}	0.324^{***}	0.297^{**}	0.134^{NS}

*, **, *** 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

	Parameter	All Fields	Cover Crops
Biological	**24-Hr Respiration**	0.350[ab]	0.254[a]
	72-Hr Respiration	0.340[b]	0.233[b]
	POXC	0.357[a]	0.243[ab]
Chemical	**Total C/N**	0.364[a]	0.300[a]
	DOC/N	0.357[a]	0.169[c]
	WEOC/N	0.326[b]	0.262[b]
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)

		Fresno/Kern Counties		Yolo County	
	Parameter	**All Fields**	**Cover Crops**	**All Fields**	**Cover Crops**
Biological	**24-Hr Respiration**	0.258[a]	0.166[a]	0.316[ab]	0.244[a]
	72-Hr Respiration	0.254[a]	0.140[a]	0.296[b]	0.221[a]
	POXC	0.271[a]	0.148[a]	0.326[a]	0.243[a]
Chemical	**Total C/N**	0.316[a]	0.180[a]	0.303[b]	0.267[a]
	DOC/N	0.169[b]	0.086[b]	0.292[b]	0.184[b]
	WEOC/N	0.299[a]	0.188[a]	0.341[a]	0.258[a]

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

FERTILIZER RESEARCH AND EDUCATION PROGRAM
CALIFORNIA DEPT. OF FOOD AND AGRICULTURE

cdfa

Department of
LAND, AIR AND WATER RESOURCES
University of California, Davis
Climate Change • Sustainable Agriculture
Environmental Quality • Landscape Processes

THE UNIVERSITY OF CALIFORNIA DAVIS
LET THERE BE LIGHT