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Soil Biology and Carbon Cycling in California Rangelands

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Book Chapter: Soil Biology and Carbon Sequestration in Grasslands
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Objectives of this talk

- Describe the effects of land use on grasslands (and oak savanna) in California
  - Potential vs. actual distribution of grasslands
  - Aspects of land use history affected by soil type
- Show how land use influences soil microbial communities and soil C
  - Disturbance gradient (intensive agriculture→relict grasslands) in the Salinas and Carmel Valleys of Monterey County
- Explain implications of soil biology for grassland restoration
  - Above- and belowground relationships

Potential grassland (and savanna) distribution by soil order in California

- Much of the land use is now intensive agriculture
  - e.g. 82% in the Great Valley
- Type conversions after fire or cropland abandonment
  - From chapparal and coastal scrub (Coast Range)
  - From *Atriplex* scrub (Tulare Basin)
- Soil orders
  - Grasslands on Mollisols only in small coastal prairies, stream terraces in narrow canyons
  - Remaining and recent grasslands tend to be on younger soils with lower soil C than Mollisols
- Effects on soil C and microbial communities?

USDA-STATSGO Database

Land use change, soil C, and soil microbial communities

Literature review (largely outside of California):

- Grasslands have a high capacity to store soil C
  - High primary productivity
  - Accumulation of litter and rhizodeposits
  - Stability of by-products produced during decomposition
- Soil C is lost when grasslands are tilled
  - Previously protected C becomes available to microbes
  - Temperature/moisture regime favors microbial activity
- Soil C increases after cropland abandonment
  - Affected by plant species composition, primary production, and management (fertilization and irrigation)
- Soil microbial and faunal communities are important for the stabilization of soil C from plant and microbial residues
  - Direct relationships among taxa are difficult to assess
  - Seek associations with ecosystem functions

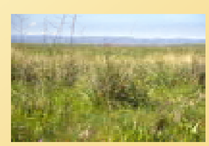
Burke et al., 1989, Guggenberger et al. 1999, Wardle et al. 2004, Sparling et al., 2006

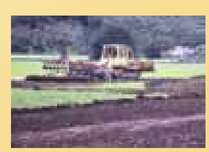
Soil Organic Matter (SOM)

- Mainly composed of C and N
- **Most abundant:** recalcitrant and protected SOM
  - humic substances and other material that is hard to breakdown
  - can be physically or chemically protected to resist breakdown
- **Much less abundant:** active SOM
  - sugars, amino acids, readily decomposable plant material, dead and live microbial cells
- Microbes break down SOM to get soluble, available C for growth and maintenance. CO_2 is produced. N is released and made available for plant growth.

Soil microbial communities along a land-use gradient on similar granitic soil types in Monterey County, CA

- Comparison of several agricultural and grassland land use types for total soil C, N, and phospholipid fatty acids (PLFA)
- Short-term response to tillage of grassland and vegetable soils
- Typical changes with transition from grassland→agriculture (Smith & Young 1975; Woods 1989; de Luca & Keeney 1994)
  - Rapid decline in soil microbial biomass and soil organic matter
  - Decreased respiration and potential N mineralization
  - Higher soil NO_3^- and NO_3^-:NH_4^+ ratios



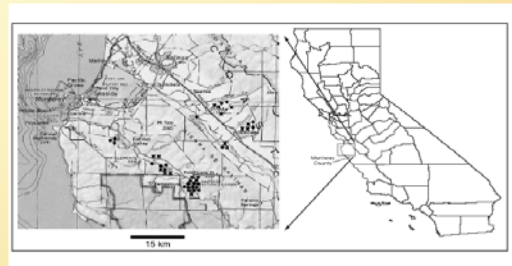


Soil microbial communities

- Most soil microbes have not been identified and have not been cultured
- Phospholipid fatty acid (PLFA) analysis gives 'community fingerprint'
- Phospholipid fatty acids are:
  - In membranes of all living cells
  - Rapidly turned over on cell death
  - Excellent signature molecules

- Microbes:
  - Produce diverse range of PLFAs => community composition
  - Total PLFA concentration is a measure of total microbial biomass
  - Specific PLFAs are associated with some particular subsets of the microbial community. *e.g.* prokaryotes, fungi, gram-positive bacteria, cyanobacteria, actinomycetes

Transect of land use types on similar granitic soils in Monterey County, CA



Land-use types along a disturbance gradient

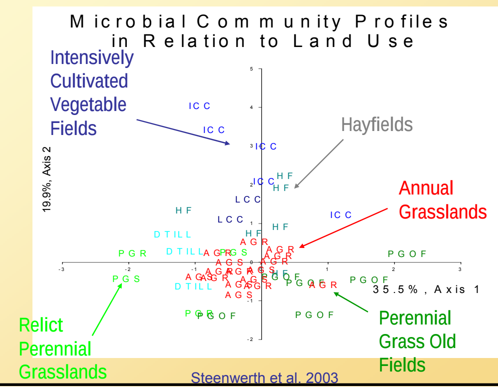
- Irrigated agriculture compared to annual grassland:
  - 60% less total C
  - 40% less total soil N
  - 65% less total PLFA (with large differences in composition)
- Annual and perennial grasslands do not show large differences

	CULTIVATED	
	Irrigated	Non-irrigated
pH	6.1-7.7	5.2-7.1
Total Carbon	1.007% -1.244%	1.336% -2.273%
Total Nitrogen	0.093% - 0.286%	0.133% - 0.208%
Total PLFA	3.3 - 19.8 *ug/g*	9.7 - 23.3 *ug/g*
	GRASSLAND	
	Annual	Perennial
pH	5.2 - 6.3	4.8 - 6.5
Total Carbon	1.297% - 5.262%	1.261% - 3.228%
Total Nitrogen	0.113% - 0.466%	0.156% - 0.314%
Total PLFA	15.7 - 48.0 *ug/g*	27.4 - 82.6 *ug/g*

Survey of 42 sites on granitic soils of similar texture and moisture in the Salinas and Carmel Valleys; 0-6 cm depth

Steenwerth et al. 2003

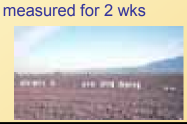
Land use types have distinctive PLFA profiles



Steenwerth et al. 2003

Simulated tillage of an annual grassland and a vegetable production soil

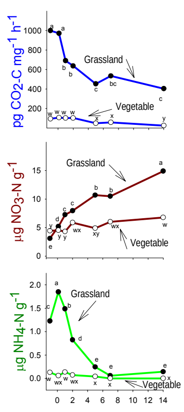
- Intact cores with identical soil texture and moisture
- Greenhouse expt. with no irrigation
- Soil sieved and replaced in cores, then 0-15 cm layer measured for 2 wks



Respiration declined after simulated tillage, and the decrease was earlier and more pronounced in the grassland soil.

Nitrate accumulated after simulated tillage in both soils, but more rapidly in the grassland soil.

Ammonium was low in both soils. Although it was initially higher in the grassland soil, it declined rapidly, and never returned to pre-disturbance levels.



Calderón et al. 2000

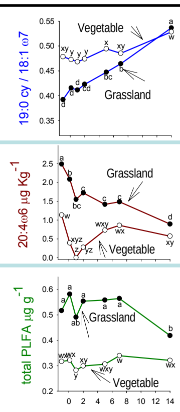
PLFA after simulated tillage, cont'd…

- Individual PLFA markers showed greater resistance and resilience to disturbance in the vegetable soil
- PLFA profiles of the entire microbial community were more variable through time in the grassland soil (not shown)

The ratio of a cyclopropyl fatty acid to its precursor, an indicator of microbial stress, showed increased stress after simulated tillage, especially in the grassland soil.

An indicator of microeukaryotes decreased rapidly in both soils after disturbance. Later recovery in the vegetable soil indicates greater resilience to disturbance than in the grassland soil.

Total PLFA, a measure of total microbial biomass, remained relatively constant in the vegetable soil, but decreased after one week in the grassland soil.

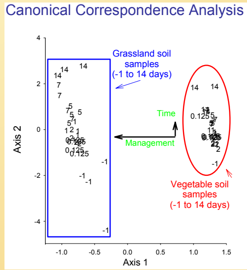


Calderón et al. 2000

PLFA profiles after simulated tillage of grassland and vegetable production soils

- Large differences between grassland vs. vegetable production time courses
  - 26 shared PLFA between grassland and vegetable soils
- Simulated tillage did not increase the similarity between the two soils
- Land use history had greater effects on PLFA profiles than short-term disturbance

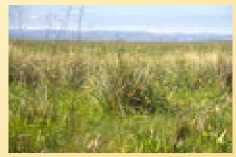
Canonical Correspondence Analysis



Calderon et al. 2000

Overview: Land use change on similar granitic soil types

- Grassland vs. tilled agricultural soils
  - Higher soil C and total PLFA in grasslands
  - Large differences in microbial communities
- Low resilience and resistance to disturbance in microbial communities from annual grassland than intensive agriculture
- Annual grasslands have similar PLFA profiles regardless of tillage history
- Relict perennial grasslands have different microbial communities than annual or restored perennial old field grasslands



Once soils are disturbed, e.g., by tillage, it may be very difficult to restore the soil microbial community to that of native relict grasslands.

Restoring native perennial grassland in California

- Notoriously difficult to establish native perennial bunchgrasses in annual grassland
  - Seedlings of native grasses do not compete well with ruderal annual grasses
- Effective method: Tillage & herbicide of annual grassland, then seeding of perennials into soil that is relatively free of competition by non-native annual grasses
  - UC Hastings Reserve
  - Mark Stromberg and Paul Kephart
  - http://www.hastingsreserve.org/NativeGrass/ChoiceAndManagement.html
- What is the effect on plant and microbial communities, and on nutrient cycling and carbon storage?

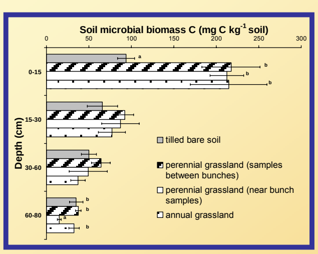
5 years after restoration of native perennial grassland began: Plant species composition

- Aboveground biomass is highest near *Nassella pulchra* bunches in the restored perennial grassland
  - Total biomass is fairly similar across the restored perennial and annual grasslands
- Restoration increased the cover of native species compared to its prior state as annual grassland
  - Other restored sites also show a weak trend toward greater cover and number of native species

	Restored perennial grassland (near bunches)	Restored perennial grassland (between bunches)	Annual grassland
Aboveground biomass ($g\ m^{-2}$)	153	49	81
Cover of native species	82%	32%	14%
No. native species	5	4	6
	7 total		
No. of exotic species	7	7	6
	7 total		

Potthoff et al. 2005

5 years after restoration of native perennial grassland began: Soil microbial biomass



- Soil microbial biomass was similar in both grassland types
- Continuous tillage causes soil microbial biomass and total C to decrease
  - Lower fungal PLFA markers than in grassland plots
- PLFA of the restored perennial grassland resembled PLFA of annual grassland, even after two years of tillage

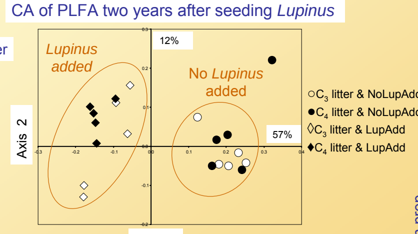
Potthoff et al. 2005

Effects of adding *Lupinus bicolor* and high C:N litter to restored *Nassella* grassland

CA of PLFA two years after seeding *Lupinus*

with perennial grass litter

with *Lupinus bicolor*



- PLFA fungal markers increased with added *Lupinus*
- Biomass, and %P of annual litter increased, and $\delta^{15}N$ decreased with added *Lupinus*
- *Nassella* little affected by adding *Lupinus*
- Little effect of adding high C:N litter

Potthoff et al. in prep

Nassella pulchra along a gradient of land use intensification

- Do native bunchgrasses cultivate the same microbial community across a gradient of land use intensification?
  - No
- Experimental approach:
  - Three *Nassella* ecosystems on similar soil types
    - Relict perennial grassland
    - Restored perennial grassland
    - Agricultural grassland
  - ± annual plants (removal) around the bunchgrasses
  - Sampled PLFA and microbial activity in fall, winter, and spring
- PLFA profiles of *Nassella* soil differed
  - Seasonally
  - Between *Nassella* surrounded by bare soil vs. annual plants
  - Between ecosystems

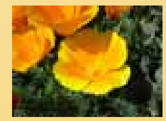
…but not consistently

- There is high variability in *Nassella*'s impact on its soil microbial communities, and on their activity
- Planting *Nassella* does not 'restore' a microbial community that resembles that of the relict perennial grassland

Steenwerth et al. 2006

Conclusions

- Land use strongly affects soil microbial communities, based on PLFA
- Short-term effects on soil microbial communities (e.g., disturbance and plant species effects) are superimposed upon a strong land use 'fingerprint'
- With time, transitions to a whole new land use regime alters soil microbial communities in a consistent way
  - Tillage and agricultural management
  - Invasion of non-native annual grasses
- It may be very difficult (impossible?) to restore the soil microbial community to that of native relict grasslands.
- Future challenges:
  - Conservation of relict grasslands
  - How to manage soil microbial communities to increase ecosystem functions, e.g., soil C storage
  - How to use soil microbial markers as indicators of compliance with policies for sustainable management



AND…….

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