Soil Carbon and Nitrogen Dynamics in Fire-Suppressed, Wildfire-Burned, and Prescribed-Burned Chaparral in the Sierra Nevada Foothills

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Research Rationale

Chaparral shrublands occur on most continents where xeric moisture regimes (wet winters, dry summers) occur, near coasts of North and South America, South Africa, Australia, and the Mediterranean Sea (Figure 1). They cover nearly 13 percent of the land area of California in the coast ranges and Sierra Nevada Foothills. High flammability, extreme fire weather, and inaccessible terrain mean that both prescribed fires and wildfires can cover huge areas, suddenly and drastically altering fundamental ecosystem processes. Rapid vegetation regrowth means that catastrophic fires can recur in 10 years or less.

Fire can provide opportunities for rapid, large-scale vegetation manipulation for range management and fire hazard reduction, but changing land uses due to increasing human populations are altering historic fire regimes and limiting fire management options. Improved understanding of how fire frequency affects above- and below-ground processes that control C storage and flow could support management decisions on fire hazard reduction, range management, and land use.

Fig. 1: Occurrence of chaparral shrublands.

Fig. 2: Sierra Nevada foothills chaparral.

Objectives

Monitor soil organic matter (SOM) dynamics within four different fire frequencies on two soil types common in Sierra Nevada foothill chaparral of California.

Materials and Methods

Location: West slope of the central Sierra Nevada Range near Moccasin, CA (120°15" LAT and 37°45" LONG), 600m elev., MAT: 14.4°C, MAP: 600mm.

Landscape Position: Shoulders and upper backslopes, 8 to 25 percent slopes

Soils: Four different cover types resulting from fire history on two very widespread soils of the Sierra Nevada foothills:

1. Fine-loamy, mixed, superactive, thermic Mollic Haploxeralfs of the Stonyford and Rescue series formed in colluvium and residuum of **metabasic igneous or sedimentary rocks**. Loam texture
2. Fine-loamy, mixed, semiactive, thermic Ultic Haploxeralfs of the Auberry series formed in colluvium and residuum of **granitic rocks**. Sandy loam texture.

Fire Frequency and Vegetation: Fire frequency identified from GIS layers prepared by CA Dept. of Forestry and Fire Protection (CDF);

FS Fire-suppressed: **No recorded fires** in last ~100 years. Dense overstory of live and dead chamise (*Adenostoma fasciculatum*) and manzanita (*Arctostaphylos* spp.) and other shrubs 3 to 5 m in height. Very sparse ground cover of annual grasses and forbs (Figure 3);

20-y 20-year frequency: **Fires in 1950, 1972, and 1992**. Dense, vigorous growth of chamise and other shrubs less than 2 meters in height regrowing in tall burned stems from 1992 fire (Figure 4);

4-y 4-year frequency: **Fires in 1997 and 2001**. Dense annual grass ground cover with sparse, regrowing chamise 1 to 2 m in height and numerous burned shrubs from the 2001 fire (Figure 5);

1-time **One-time recent fire in 2001** in fire-suppressed chaparral. Dense regrowing chamise, sparse annual grass and forb ground cover, numerous burned shrubs from 2001 fire (Figure 6);

Soil Sampling: Composite homogenized litter and soil samples from two depth increments (0-5 cm and 5-20 cm) collected along 6 transects in August 2004. Soils stored at 5°C until lab analysis.

Measurements

Litter: Total mass per m^{-2}, Total N (%), lignin (%);

Soil:

- SWC (%);
- Soil texture;
- **Carbon:** Total Organic C (%), C mineralization (mg CO_2-C g^{-1} soil 28 $days^{-1}$), dissolved organic C (ug C g^{-1} soil);
- **Nitrogen :** Total N (%), N mineralization (ug inorg N-g^{-1} soil), potentially mineralizable N (PMN) (ug NH4+-N g^{-1} soil 14 $days^{-1}$), inorganic N (ug g^{-1} soil);

Fig. 3: Fire Suppressed

Fig. 4: 20-year: '50,'72,'92

Fig. 5: 4-year: '97, '01

Fig. 6: 1-time burn in 2001

Results and Discussion

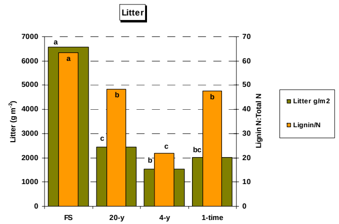

Fig 7: Litter mass and quality. Different letters denote significant differences (n = 6).

Any occurrence of fire in chaparral reduces quantity and improves quality (decomposability) of surface organic residues. Significant build up of highly recalcitrant litter in FS leads to C and N fixation in forms and locations (soil surface) not accessible by microbes and plants. In contrast, 4-y surface litter is largely derived from deposition of easily decomposable senescing annual grasses and forbs.

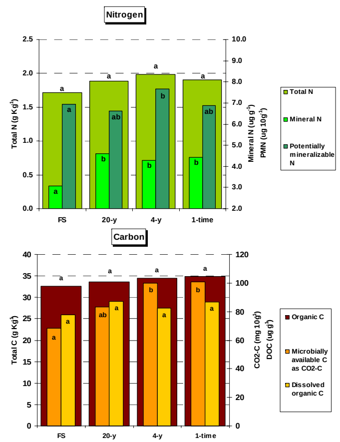

Fig 8: Soil carbon and nitrogen, 0- to 5-cm depth, both soil types (n = 12).

When averaged across soils, fire does not affect soil total N, but enhances N mineralization in all fire treatments and potential N availability in the 4-y treatment. Higher litter quality and considerable fine, near-surface root production likely contributes to soil PMN pool size on these sites.

When averaged across soils, fire does not affect soil TOC or DOC concentrations. Soil from areas burned most recently have elevated mineralizable C pools suggesting greater C availability to microbes than in FS or 20-y soils. Stores of mineralizable C in soils exposed to fire every 20 years are intermediate between the recent fire soils and the FS soils, indicating a shift toward build up of more recalcitrant C pools derived from transition toward more woody vegetation.

Table 1: Mean concentrations of soil C and N fractions by soil type and depth (n = 6).

		C:N				Total N				Total Organic C				CO_2-C			
		Metabasic		Granitic		Metabasic		Granitic		Metabasic		Granitic		Metabasic		Granitic	
						g Kg^{-1}								mg g^{-1}			
0-5cm	FS	18.2	a†	19.8	a	1.90	c	1.53	ab	34.7	b	30.5	a	884	b	485	b
	20-y	17.5	a	18.0	b	1.92	bc	1.85	a	33.6	b	33.7	a	980	b	687	ab
	4-y	17.6	a	17.1	b	2.18	ab	1.78	ab	38.4	ab	30.5	a	1257	a	738	a
	1-time	18.1	a	18.1	b	2.55	a	1.48	b	46.6	a	27.0	a	1134	ab	776	a
5-20 cm	FS	16.7	a	16.2	ab	1.03	b	0.62	c	17.3	a	9.7	b	359	a	157	b
	20-y	15.1	a	14.6	b	1.08	ab	1.02	a	16.8	a	15.0	a	502	a	247	a
	4-y	15.1	a	14.5	b	1.10	ab	0.80	b	16.7	a	11.6	ab	419	a	244	a
	1-time	16.2	a	16.9	a	1.27	a	0.80	b	20.8	a	13.8	ab	591	a	351	a

		Potentially mineralizable N				Mineral N				Dissolved Organic C			
		Metabasic		Granitic		Metabasic		Granitic		Metabasic		Granitic	
						ug g^{-1}							
0-5cm	FS	78.7	a	60.0	b	2.9	b	3.2	b	79.7	a	75.4	a
	20-y	60.3	a	72.2	ab	3.9	a	5.3	a	79.7	a	94.5	a
	4-y	75.2	a	78.2	a	3.3	a	5.3	a	84.3	a	80.4	a
	1-time	62.7	a	69.5	ab	4.3	a	4.4	a	90.0	a	77.5	a
5-20 cm	FS	20.5	b	13.5	b	1.8	ab	1.1	c	47.1	b	57.2	a
	20-y	20.5	b	30.8	a	1.6	ab	2.5	a	45.5	b	54.9	a
	4-y	28.3	ab	15.5	b	1.5	b	2.0	ab	50.4	ab	53.9	a
	1-time	39.1	a	22.4	ab	2.2	a	1.8	b	62.6	a	51.1	a

† Different letters indicate significant differences among treatments within soil types.

Green print indicates significant differences between soil types within treatments.

Soil type: Metabasic soils have 50 to 80 percent more mineralizable C than granitic soils. The same soils appear to more efficiently retain TN and some TOC at greater depths. Very low DOC in both soils indicate efficient C utilization and incorporation in microbial or SOM pools. Greater mineral N in granite in combination with comparable PMN pools suggest that more sandy soils may create environments conducive to SOM mineralization and N losses at the onset of the wet season.

Fire frequency X soil: Greater available C pools in frequent and recent fire treatments in metabasic soils increase belowground TOC sequestration by 20 to 30 percent. There is not evidence of the impact of increased available C on TOC in granitic soils.

Conclusions

- Chaparral management that incorporates frequent low-intensity prescribed burns not only reduces fire hazard and smoke production, but also improves belowground C sequestration;
- Reintroduction of moderately frequent fire (between four- and 20-year frequency) to this ecosystem should yield multi-level benefits of improving resistance to fire, resilience, and sustainability, while possibly improving biodiversity and hydrological attributes;
- Improved stand structure and ecosystem biochemistry from the 4-y fire treatment suggests that relatively frequent burning is desirable, but it may not be feasible in some areas. Extending the fire frequency to 20 years does not generate the desirable effects; fire effects are no longer present;
- Estimates of the effects of fire management on belowground C stores vary with site geology and, therefore, need to be considered in determinations of ecosystem C budgets and C flow;
- To further test these concepts we are conducting ongoing studies of C and N dynamics, soil morphology, greenhouse gas emissions, vegetation dynamics, runoff and erosion, and the feasibility of establishing native perennial plants after fires in fire-suppressed shrublands (little or no annual seedbank). We are working closely with BLM and CDF to plan small-scale prescribed fires on our study sites.

Acknowledgments

We greatly appreciate field and laboratory assistance from Mary Innes. We are grateful to Ken Hood of the Bureau of Land Management, Kit Perlee of the City and County of San Francisco Hetch Hetchy Water and Power, and Andy McMurry of CDF for identifying and providing access to sites and fire history information. This project is funded by the University of California Kearney Foundation for Soil Science.

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