Effects of pyrolysis temperature and soil depth on pyrogenic carbon dynamics from a forest soil of Sierra Nevada, California

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1. INTRODUCTION

Fire transforms soil organic matter (SOM) into stable forms of organic carbon compounds rich in condensed aromatic rings collectively known as pyrogenic organic C (PyC). Wildfires are becoming larger and more catastrophic in the Western US, likely transferring more PyC to soils. However, the factors controlling the dynamics of PyC and its influence on 'native' SOM mineralization rates are not fully understood. We addressed this gap in PyC research by using a stable isotope (^{13}C) labeling technique to trace the fate of ^{13}C-labeled PyC produced from *Pinus banksiana* into two C pools (CO_2 and dissolved C) in surface and subsurface soils. This allowed us to answer the following questions:

- **How are mineralization rates of PyC and its losses from soils as dissolved PyC (DPyC) affected by pyrolysis temperature and soil depth?**
- **How do the additions of PyC to soils affect the mineralization rates of 'native' SOM. Are these effects also influenced by pyrolysis temperature and soil depth?**

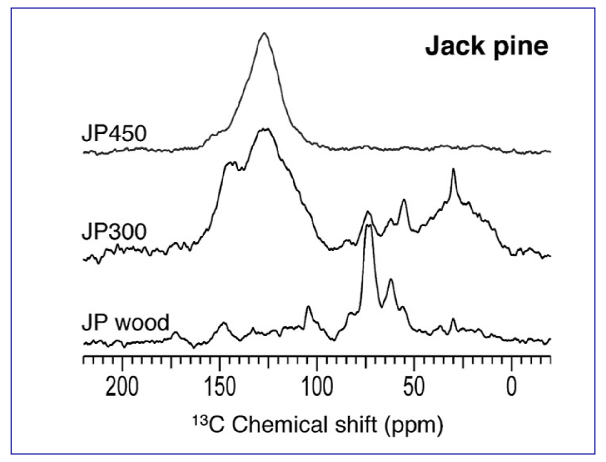
2. MATERIALS AND METHODS

7-month laboratory incubation study

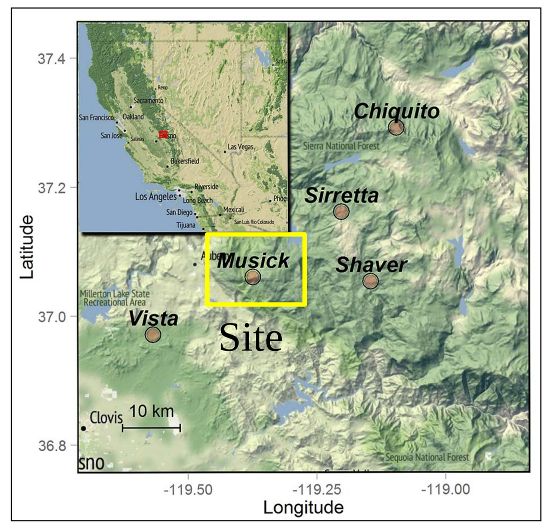
- We used dual-labeled (^{13}C and ^{15}N) jack pine PyC produced at 300°C and 450°C (Table 1, Hatton et al. 2016).

Sample	Yield	C	N	O	H	C/N	H/C	O/C	^{13}C	^{15}N	$\delta^{18}O$	Skeletal density	Envelope density	Porosity	BET-N_2 SA
	% of initial	g kg^{-1}				Mass ratio	Atomic ratio		Atom%		‰	g cm^{-3}		%	m^2 g^{-1}
JP300	45	669	5.4	286	46	124	0.8	0.3	2.37	18.8	20.8	1.33	0.33	75	4.3
JP450	27	786	5.4	197	29	146	0.4	0.2	2.33	18.9	15.2	–	–	–	13

Table 1. Chemical composition and physical properties of PyC 300 and PyC 450. Modified from Hatton et al. (2016)

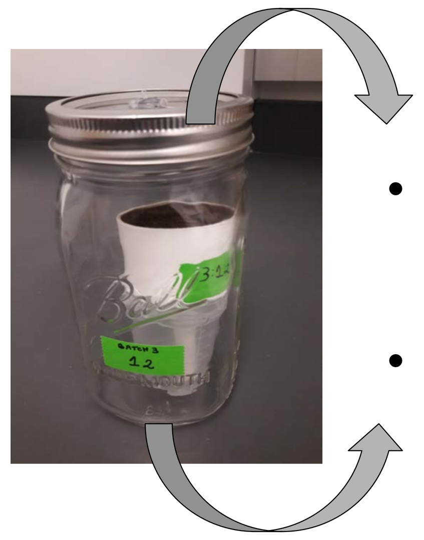


DPMAS ^{13}C NMR spectra obtained from $^{13}C/^{15}N$-enriched PyC 300 and PyC 450 (Hatton et al. 2016)



• Surface (0-10 cm) and subsurface (50-70 cm) forest soils (Musick series; fine-loamy, mixed, mesic; Ultic Haploxeralf, Dahlgren et al. 1997) were incubated with and without added PyC;

• Incubation was conducted in the dark at 55% soil field capacity and 25°C.

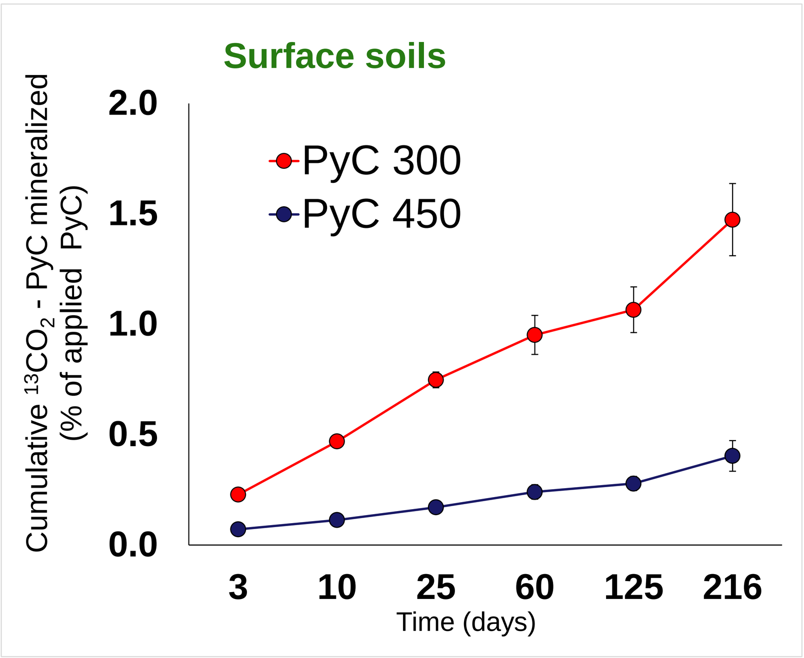


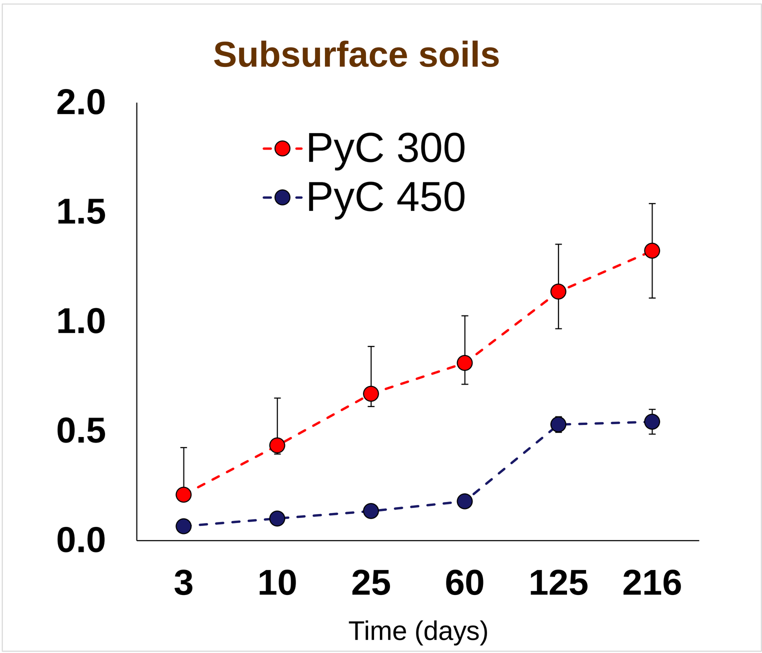
Measurements

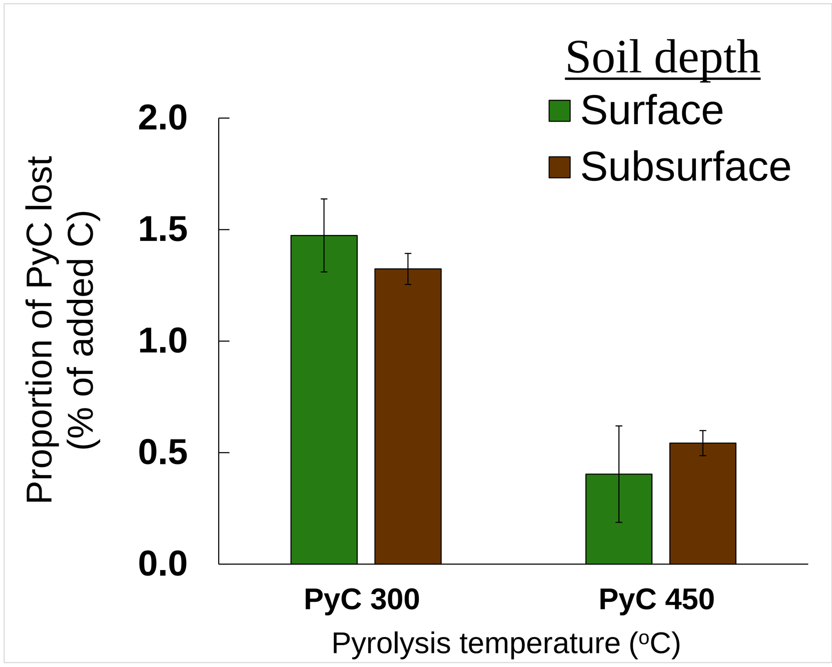
- ^{13}C-CO_2 was measured periodically to determine the proportion of PyC in total CO_2 respired from soil.
- ^{13}C-DOC was measured once a month to determine the proportion of dissolved PyC in total DOC lost from soil during leaching (<0.45 µm particle size).

3. RESULTS AND DISCUSSION

PyC losses from soil as CO_2 after 7 months of incubation



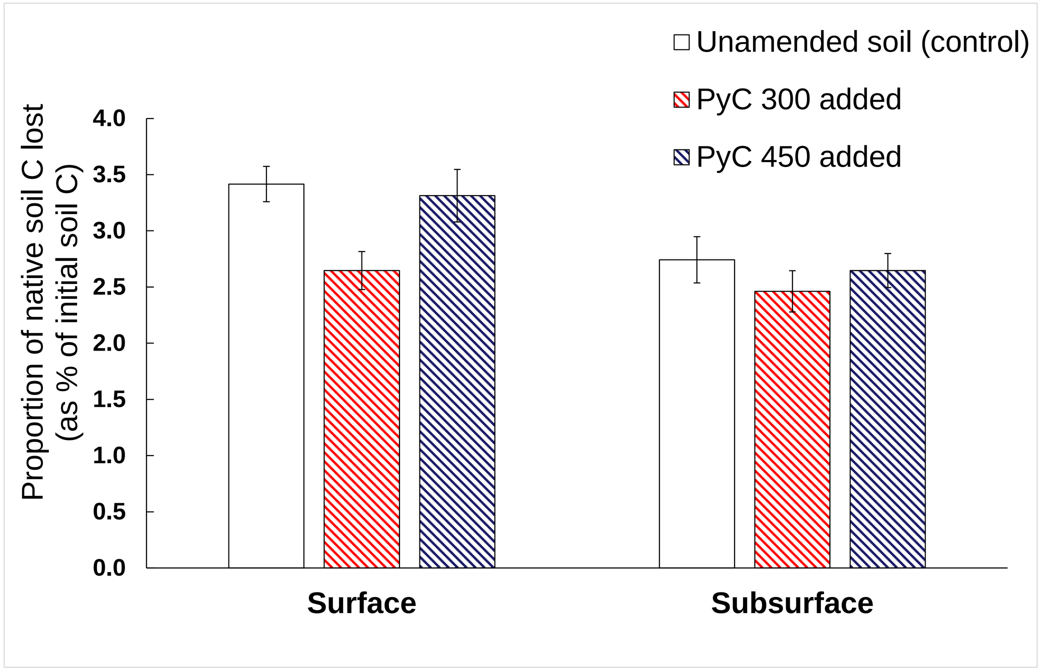




Values shown are means ± standard errors (n = 6).

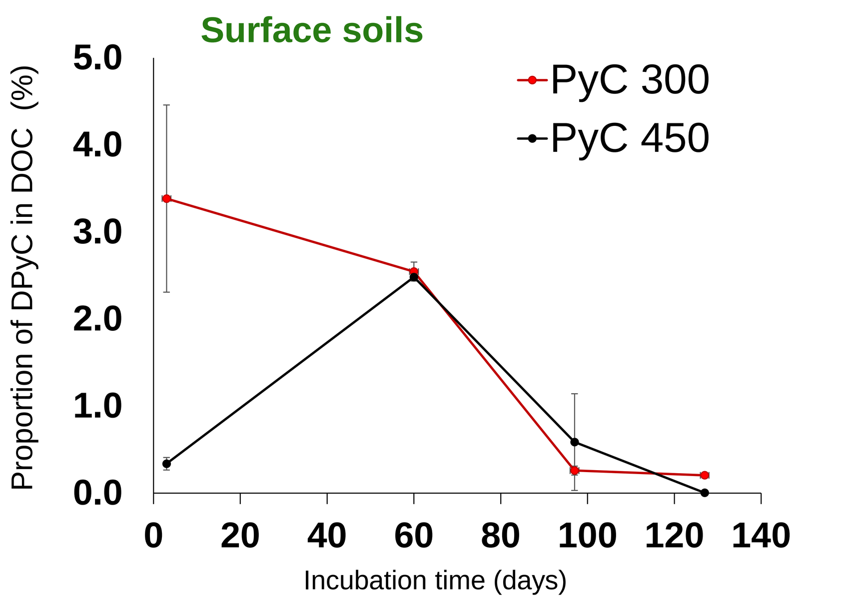
- PyC formed at 300°C mineralized faster than that formed at 450°C, whereas soil depth had no effect on the mineralization rates of PyC.
- Condensed aromatic structures were more prevalent in PyC 450 than in PyC 300 (Hatton et al. 2016), which likely explains the apparent greater stability of PyC formed at 450°C compared to PyC formed at 300°C.

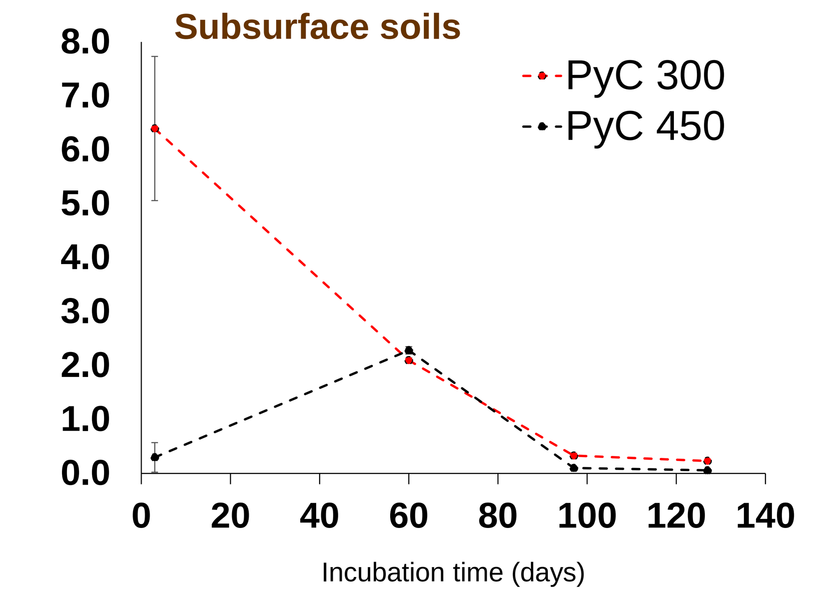
Total losses of 'native' soil organic matter

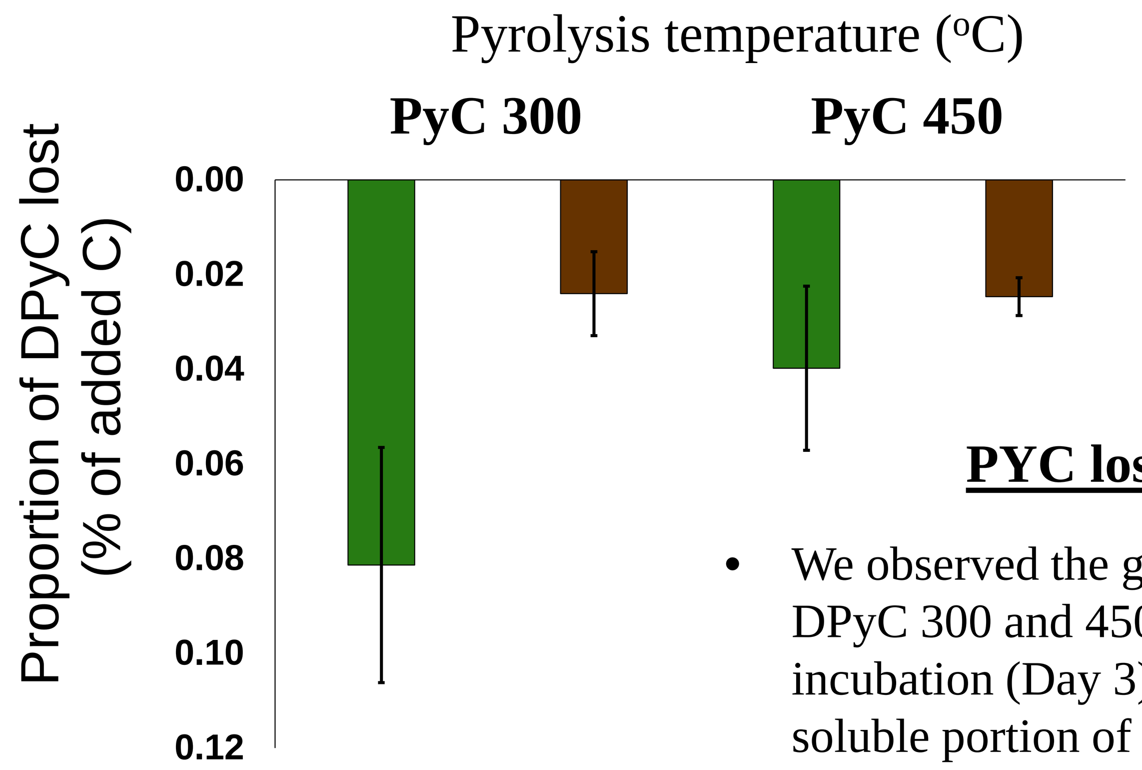


- The addition of PyC 300 significantly decreased the proportion of native SOM mineralized from surface soils.
- It is possible that the addition of PyC 300 to soils led to significant shifts in microbial community structure, with microorganisms preferentially degrading PyC 300 over native SOM.

Total PyC leached from soil as dissolved PyC after 4 months of incubation







Values shown are means ± standard errors (n = 6).

PYC losses as DPyC

- We observed the greatest difference between DPyC 300 and 450 at the early stage of the incubation (Day 3), when most of the soluble portion of PyC was leached from the soil.
- After 4 months of incubation, total losses of PyC 300 as DPyC was greater in surface than in subsurface soils (P=0.012), likely due to sorptive interactions of PyC with reactive minerals (i.e. Fe and Al hydroxides) in subsurface soil. This likely contributed to the retention of DPyC in subsurface soil.
- In surface soils, total losses of PyC as DPyC were significantly greater for PyC 300 than for PyC 450 (P=0.021), likely because presumably soluble O-containing and aliphatic functional groups were higher in PyC 300 than in PyC 450 (Hatton et al. 2016)

4. CONCLUSIONS

- Our results suggest that formation temperature affects the chemical and physical characteristics of PyC, therefore controlling the behavior of PyC in soils.
- PyC formed at 450°C is more stable in soils than PyC 300°C. This was reflected in losses of PyC as both CO2 and DOC.
- Additions of PyC formed at 300°C inhibited the mineralization rates of native SOM
- Our results suggest that one year after fire or application in soil, PyC formed at lower temperatures will degrade faster than that formed at higher temperatures.
- These results highlight the importance of considering formation temperature when using PyC (or biochar) as a mean to sequester carbon in soils.

Future directions:

Analysis:

- ^{13}C- phopholipid fatty acids
- Solid and liquid-state ^{13}C-NMR
- Density fractionation of SOM

ACKNOWLEDGMENTS

UC-Davis, Stable Isotope Facilities
Funding for this study was provided by NSF CAREER grant (to A.A.B.).

References
Dahlgren et al. *Geoderma* (1997)
Hatton et al. *Biogeochemistry* (2016);