Examining the effects of 18th-19th century charcoal production in soil-water repellency in northwestern, Connecticut

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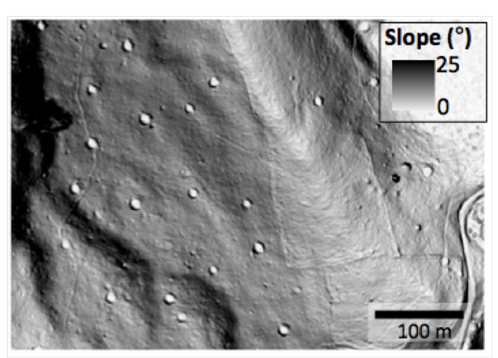
Kelly Flannery[1] (kelly.e.flannery@uconn.edu); William Ouimet[1,2] (william.ouimet@uconn.edu); Eli Egan-Anderson[2] (eli.egan-anderson@uconn.edu); Sarah Vitale[3](vitalesa@uwec.edu)
[1]Center for Integrative Geosciences, University of Connecticut, Storrs, CT; [2]Department of Geography, University of Connecticut, Storrs, CT; [3]Department of Geology, University of Wisconsin- Eau Claire, Eau Claire, WI

Abstract - Overview

Burned and charred organic material within soils can affect water retention and infiltration, and therefore may be related to increased runoff, erosion, and flooding. While the effects of burned soils following wildfire events have been studied around the world, there has been less research on the effects of increased charcoal and burned organic material within soils due to anthropogenic land use changes. This study shows how remnants of charcoal in soil from 18th-19th century charcoal production throughout northwestern Connecticut alters infiltration rates and soil water repellency. Charcoal production during this time period was accomplished by making platforms on which mounds were constructed to pyrolyze cut trees into charcoal. These sites, which we call relict charcoal hearths (RCHs), can be found throughout the northeast region and to date over 20,000 have been located. Each RCH is ~8-16 m in diameter and typically consists of one or more soil layers that are very dark and exhibit large quantities of charcoal fragments and burned organic material. Soil samples consisted of 6.5 cm diameter, 5.5 cm thick rings, and were collected from both RCHs and sites adjacent to RCHs at multiple depths within individual soil pits. In total, we analyzed 127 soil samples, 92 of which had clear amounts of charcoal and burned organic material, while 35 soil samples analyzed did not. For each soil ring, we calculate the water-repellency index (R) by comparing two wetting liquids (water vs. ethanol) with differing soil-liquid contact angles following the methods of Young et al., 1997. Our results indicate that charcoal and burned organic matter present in the RCH samples alter properties of the soil and leads to a different soil-water repellency. The charcoal laden aggregates exhibit a higher mean R-index and greater range in R-index tending towards higher values. There also appears to be variation with depth. Overall, this study shows that land use that occurred over 125 years ago continues to have a lasting impact on soil properties today.

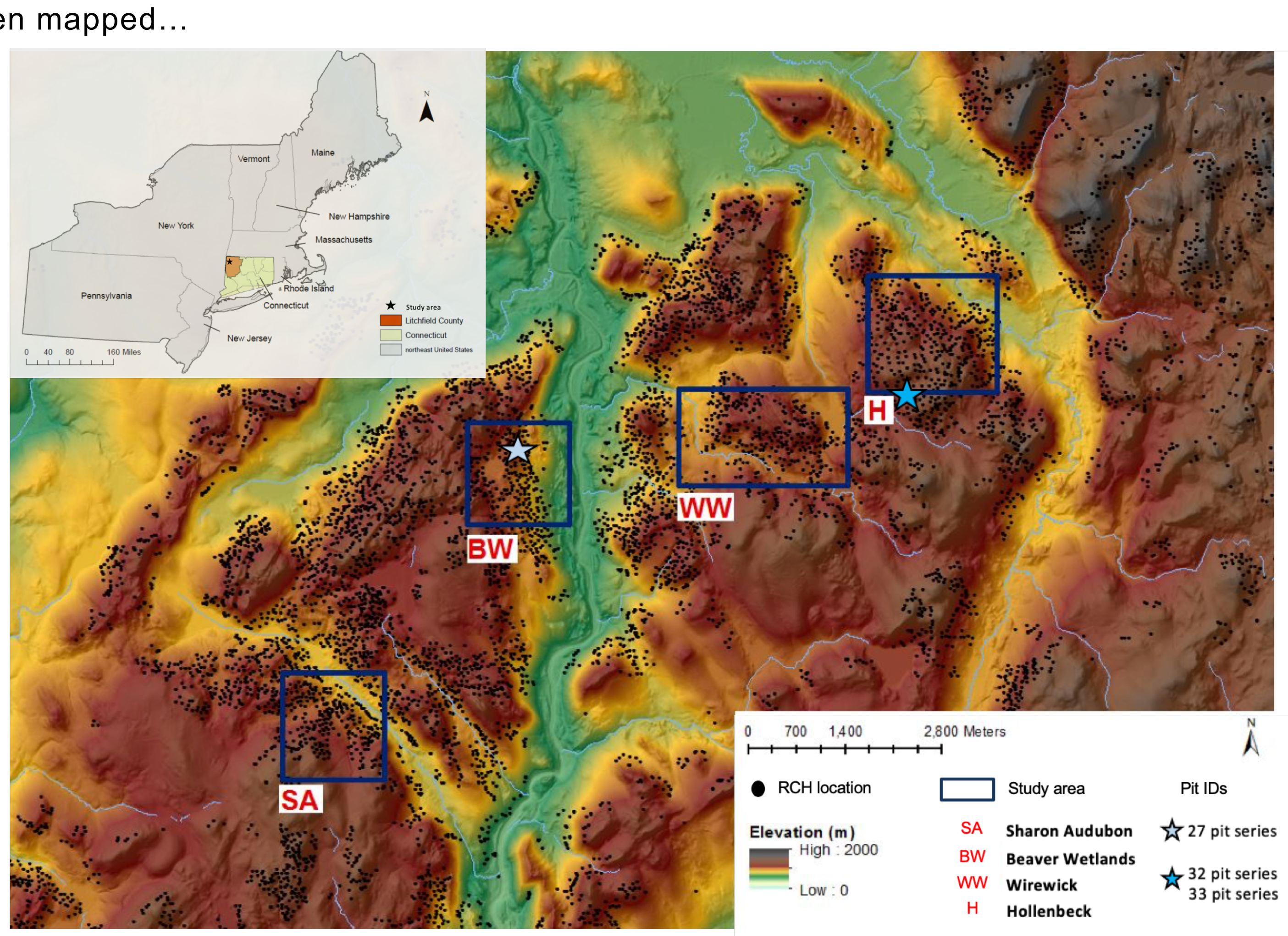
Background - Relic Charcoal Hearths (RCH)



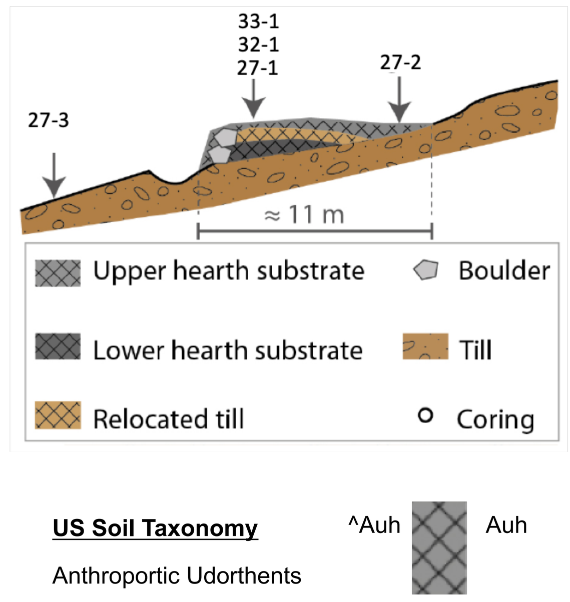
In woodlands across the northeast United States, colliers gathered and stacked wood on charcoal burning platforms and could produce up to 6,000 bushels of charcoal at larger operation sites. Charcoal fueled industrial services, such as the iron industry, and therefore was an important economic resource. As technology advanced away from charcoal burning in the second half of the 19th century, platforms were left unused. RCHs are the remnants of 18th-19th century charcoal production. RCHs appear on the landscape as raised mounds carved out of the hillslope. In LiDAR, RCH's are expressed topographically as round mounds with flat tops and defined edges. They are visible in slope and/or hillshade map view. Clusters of RCHs are seen throughout the northwestern Connecticut and provide insight towards the scale of the historic charcoal and iron industry. These clusters tend to populate modern day agricultural land.

Study area

Soil samples located in northwest Connecticut, where approximately 22,000 RCH sites have been mapped…



Sample collection



Soil samples were collected from different areas within and surrounding the RCH. For each soil pit depth, multiple sample rings were collected. Sample rings are 7 cm in diameter and 5 cm in height. The cross section architecture of a representative charcoal hearth shows the material we would expect to find within each sample (adapted from Hirsch et al., 2017).

RCH samples in the downslope position vary between Auh horizon, Auh/B and B/Auh horizon, and B horizon as depth increases. Auh is manmade humic soil and is also present in the upslope position of the hearth. Samples outside if the hearth do not have an Auh horizon.

Lab Methods

Setup

Each sample was tested with both a water and an ethanol mixture to calculate its repellency index. We measured the sorptivity of water and ethanol by timing the rate of infiltration under vacuum. This timing process was repeated five times, with both water and ethanol, for each sample in different locations. These ten measurements were used to calculate each ring's average repellency index.

$$R = 1.95\left(\frac{S_e}{S_w}\right)$$

Where *R*= repellency index
S_w= Sorptivity of water
S_e= Sorptivity of ethanol mixture

We then calculated the average repellency index and standard deviation from each pit at a given depth. These measurements were compared graphically to show how the repellency index differs between varying depths within three sample locations. In soils with a higher charcoal content, the rate of infiltration was slower and samples absorbed less fluid (g).These findings support that charcoal laden soils tend to have higher repellency index values.

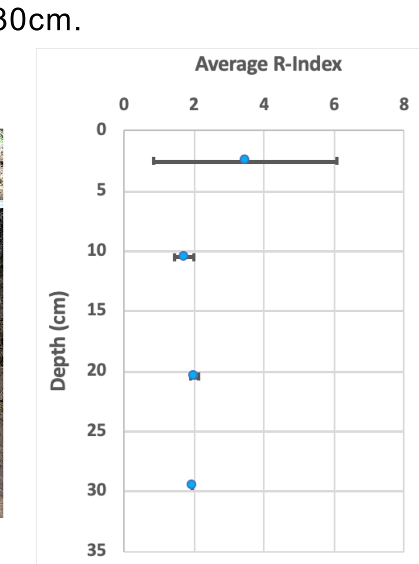
Results

RI Data Table

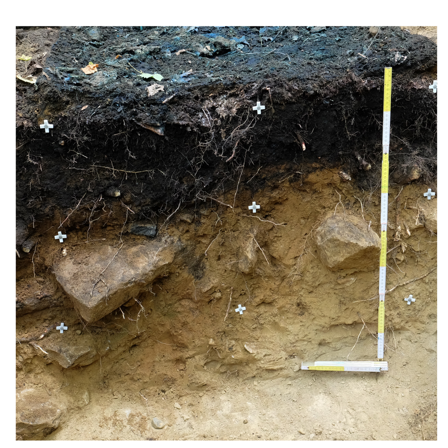
RCH Site?	Pit ID	# of samples	Soil type	Depth	Avg. R	σ
Yes	27-1	4	Auh	0-5 cm	3.47	2.62
Mix	27-1	9	B/Auh	08-13 cm	1.72	0.26
Yes	27-1	7	Auh	18-23 cm	2.01	0.10
Yes	27-1	1	Auh	27-32 cm	1.96	0.00
Yes	27-2	8	Auh	0-5 cm	3.19	1.98
Yes	27-2	10	Auh	8-13 cm	2.86	0.81
Mix	27-2	10	Auh/B	20-25 cm	2.18	1.69
No	27-2	9	B	36-41 cm	1.68	0.29
Mix	27-3	7	Ab	0-5 cm	1.89	0.09
No	27-3	8	B	9-14 cm	1.75	0.32
No	27-3	4	B	25-30 cm	1.58	0.32
Yes	32-3	6	Auh	10 cm	2.22	0.13
Mix	32-3	5	B/Auh	26 cm	2.85	1.73
Yes	32-3	6	Auh	36 cm	1.82	0.15
No	32-3	7	B	60 cm	1.78	0.03
Yes	33-3	6	Auh	10-15 cm	1.97	0.41
Yes	33-3	6	Auh	30-35 cm	1.52	0.16

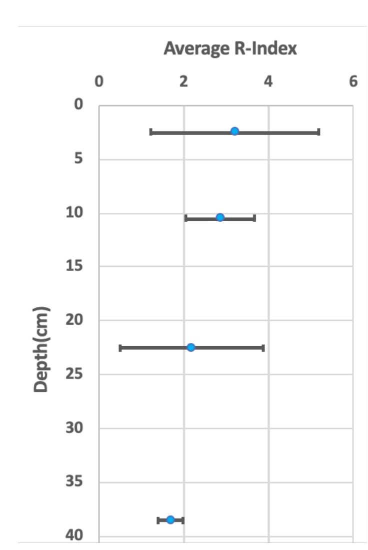
*grey represents the presence of charcoal pieces, dark gold represents mixed layers, and orange tones represent soils that are unaffected by charred material.

Pit 27-1 -- On a RCH, downslope position, multiple Auh layers, sampled to 30cm.



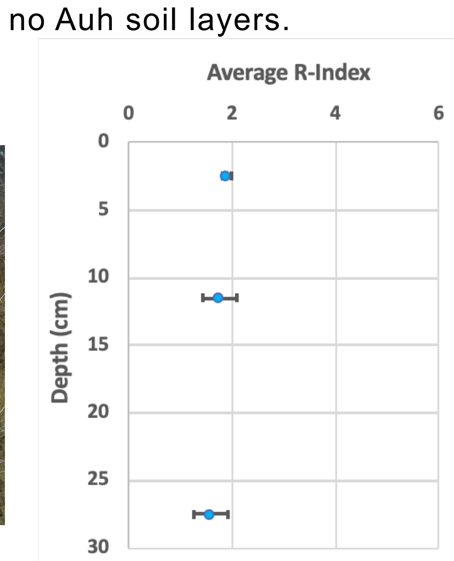
Pit 27-2 – On a RCH, upslope position, thinner Auh layer. Sampled to 41cm.



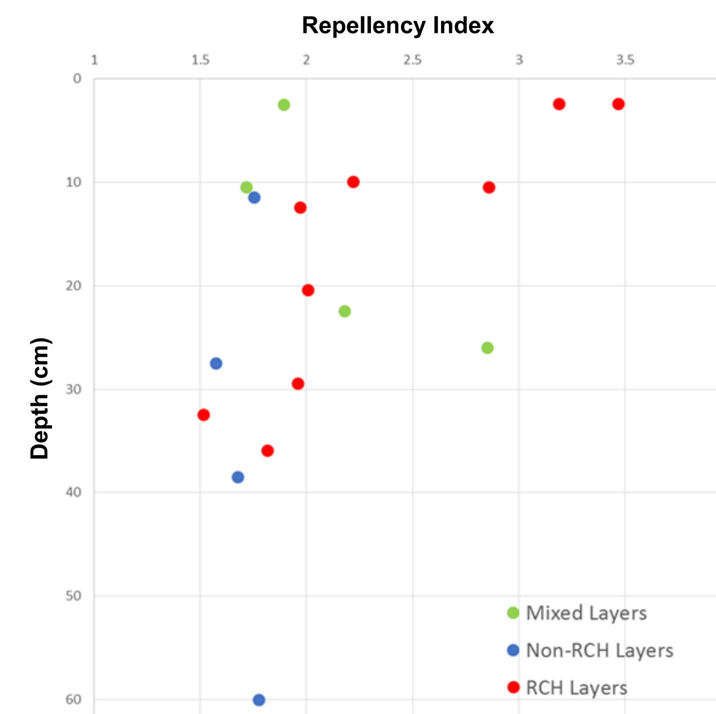


Pit 27-3 – Not on a RCH, no Auh soil layers.

**This photo is of a comparable pit adjacent to an RCH.*



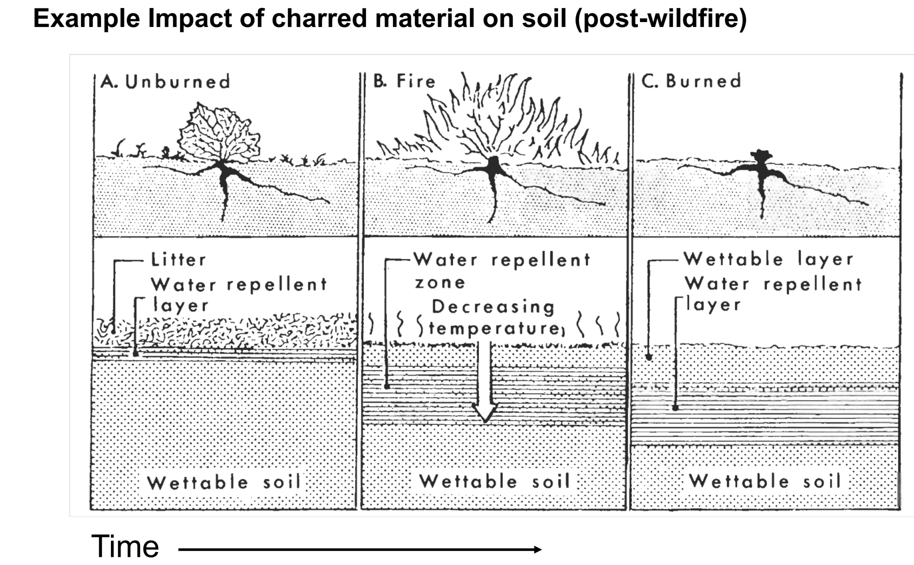
Repellency index by depth



Average measurements associated with non-RCH layers all show a repellency index value less than 2.0. This supports that B soils tend to have a higher infiltration capacity. Mixed layers (containing Auh/B soil and B/Auh soil) from our samples show some variance in repellency index values. These differences can be linked to the proportion of Auh-to-B soil within each sample and the composition of the sample's surface. The makeup of the surface may not be representative of the entire sample, and therefore can lead to infiltration rate variance. RCH layers show a wide range of variability and tend to have higher repellency index values. At shallow depths (0-5cm), measurements support that Auh soil would have high repellency index values and low infiltration capacity. Variance in RCH layers can again be attributed to sample ring composition. Further studies on this topic should include more samples from each depth to decrease this variation.

Implications

Example Impact of charred material on soil (post-wildfire)



Charred organic material changes the physical properties of soil. Samples from RCH pits contain charcoal pieces and display higher repellency indexes. These measurements inform our understanding of soils affected by fires. After a fire, a water repellent layer forms because of large quantities of burned organics. (DeBano, 1981).

Across the northeast, relic charcoal hearths alter the landscape's soil chemistry. There is a high concentration of RCHs in the agricultural lands of northwestern, Connecticut. The historic charred materials in RCH samples continue to display repellent properties. This increased repellency means that RCH sites are susceptible to runoff when rainfall exceeds the infiltration capacity. Runoff in agricultural land carries harmful agricultural pollutants into watersheds and can erode soils, causing instability within the landscape. Understanding the impact of charred materials in large areas can be used as an analogy for western region United States. Forest fires are an environmental threat to large sections of the United States. The 2018 Camp Fire in Butte County, CA burned ~154,000 acres of forest. Charred material from this fire decreases the soil's infiltration rate and leads to increased runoff. In Butte County, runoff is an environmental hazard because it carries a mixture of metals, toxins, and other chemicals from the air, ash, and debris into the region's creeks and rivers (Bourzac, 2018). Materials from affected areas drain into watersheds and contaminate both the water supply and aquatic ecosystems. Large areas of water repellent land are susceptible to increased runoff and erosion and can be harmful to the community. As we further our knowledge on the scale and repellency of RCHs, we can also learn how to best mitigate their effects.

Key Takeaways

- The northeastern landscape reflects the prominence of charcoal production in the 18th-19th century and its continued effects on soil water repellency.
- The remnants of 18th-19th century charcoal production are known as relic charcoal hearths (RCH).
- Samples within and adjacent to RCH sites consist of variable soil types that each effect sorptivity rates in different ways.
- Soils within RCH sites have variable repellency index measurements that tend to be higher in relation to their charcoal concentration.
- When heavily concentrated, RCH pits alter soil chemistry of a vast landscape.
- Charred material in soils decreases water retention and potentially causes issues like increased runoff, erosion, and flooding.

References

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