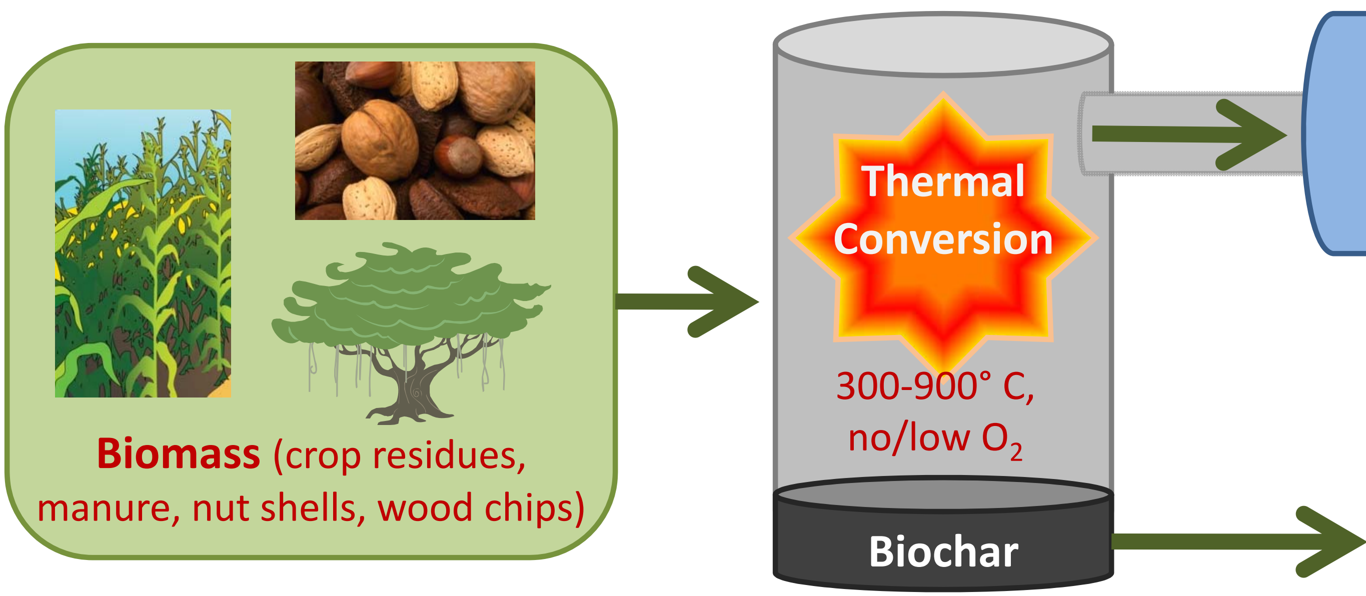
Evaluating Biochar's Potential in California Agriculture

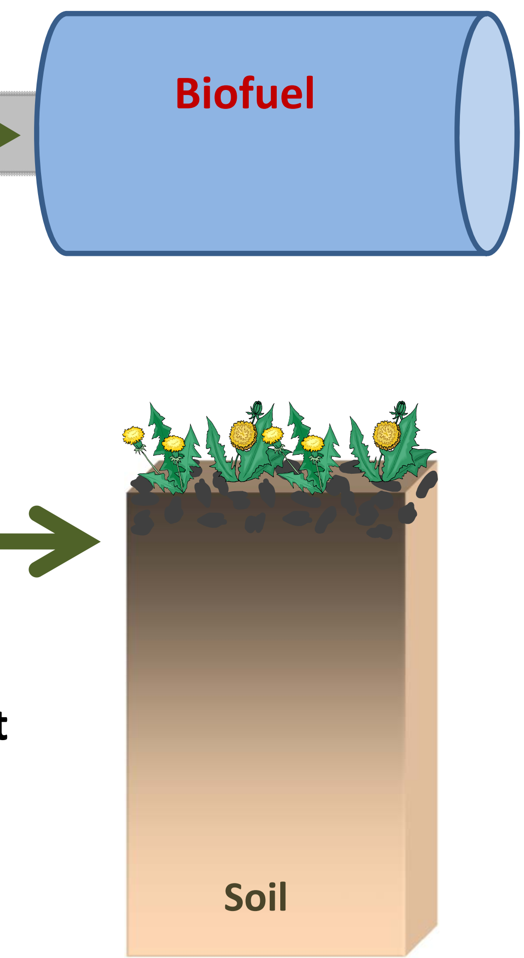
Sanjai J. Parikh

University of California – Davis

What is Biochar?

Biochar is charcoal created from biomass, and differs from charcoal only in the sense that its primary use is not for fuel. Typically used as a soil amendment.





Biochar may be produced intentionally as a soil amendment or as a waste byproduct in the production of bioenergy.

Biochar properties are a function of feedstock material production parameters.

Why Biochar?

"Terra Preta de Indio" – Amazonian Black Earth

- Brazil and other parts of South America
- 500 to 2500 yrs B.P.
- Addition of charcoal (black carbon/biochar) for soil management
- Today, high organic matter content and more fertile

http://www.biochar-international.org/files/graphics/terra-preta.jpg

Potential Reasons to Use Biochar in Soil

- Carbon Sequestration
- Drought Resilience
- Soil Fertility
- Reduce Nutrient Leakage
- Crop Yield and Quality
- Greenhouse Gas Emissions
- Soil Remediation
- Soil Microbiology
- Raise soil pH

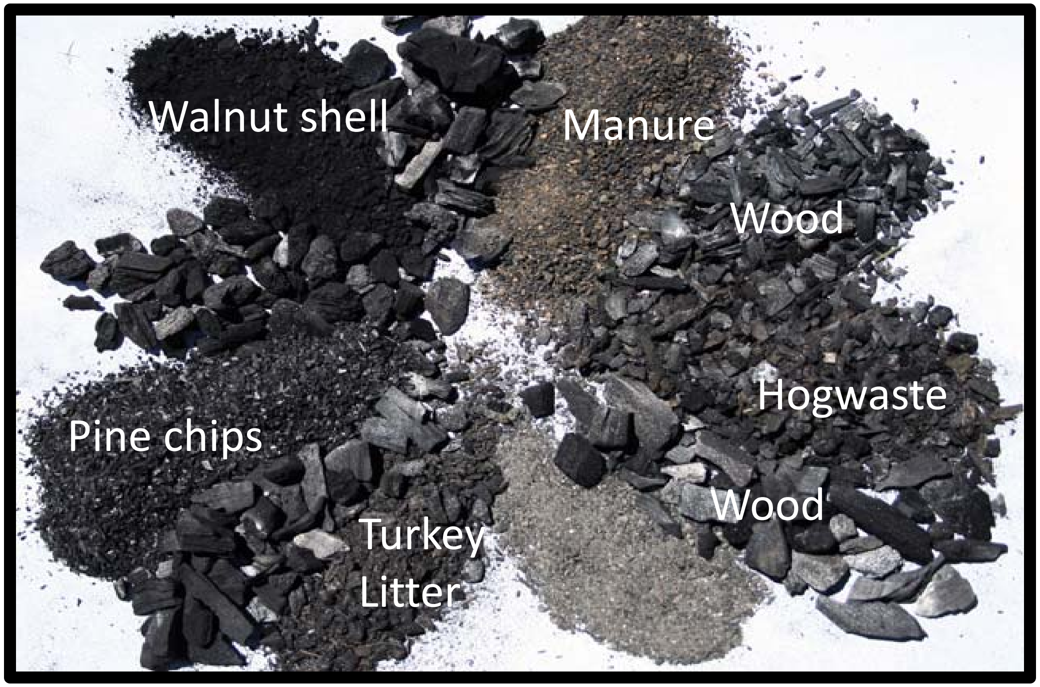
- Benefits inconsistent
- Multiple variables
- Some potential drawbacks
- Biochar is not a specific product → umbrella term

How do biochars differ?

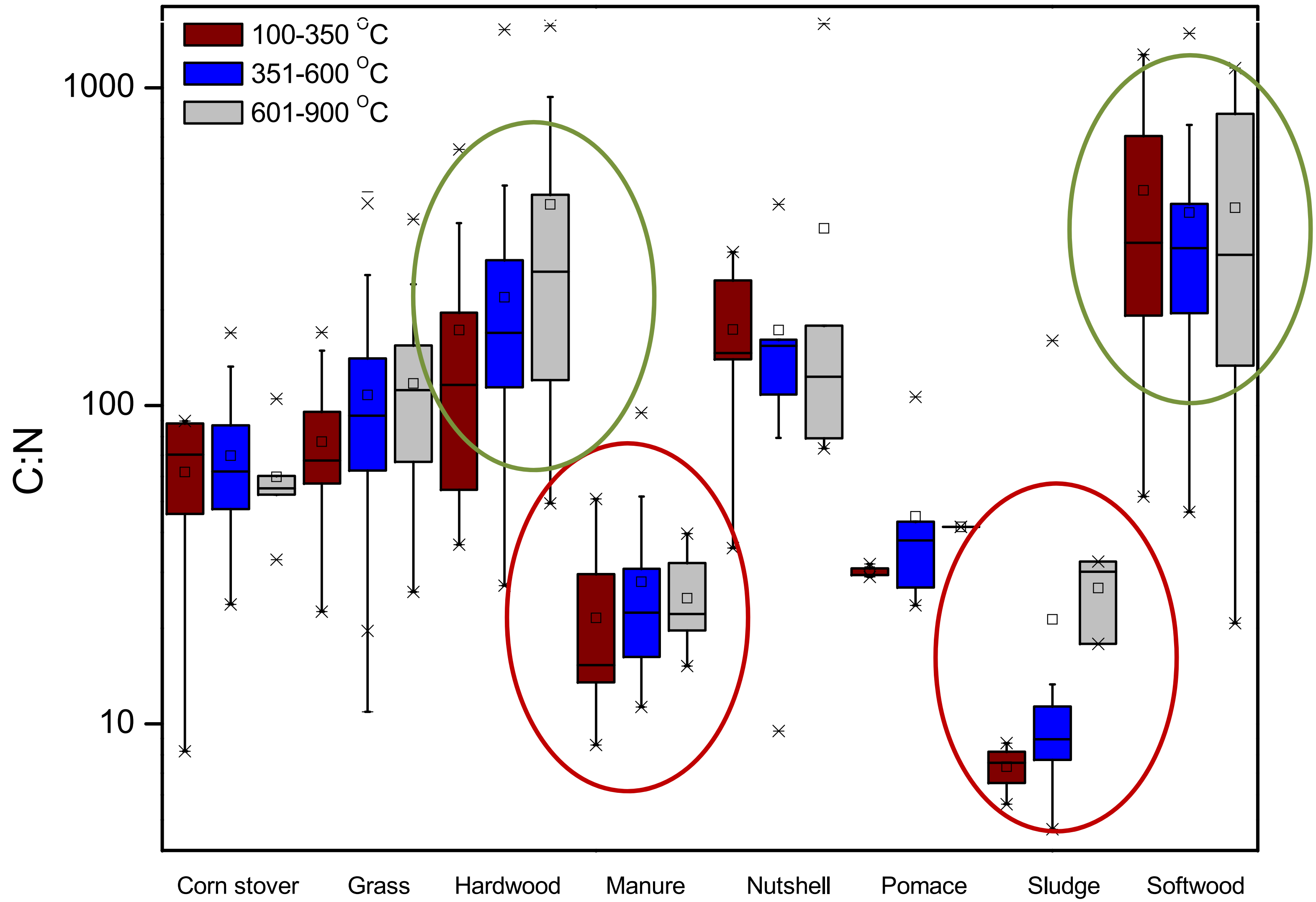
Some Key Characteristics

– pH
– H/C ratio
– C/N ratio
– Porosity
– Elemental composition
– Surface area
– Ash content
– Cation exchange capacity (CEC)
– Water holding capacity

- function of production temperature, production method, residence time, and feedstock

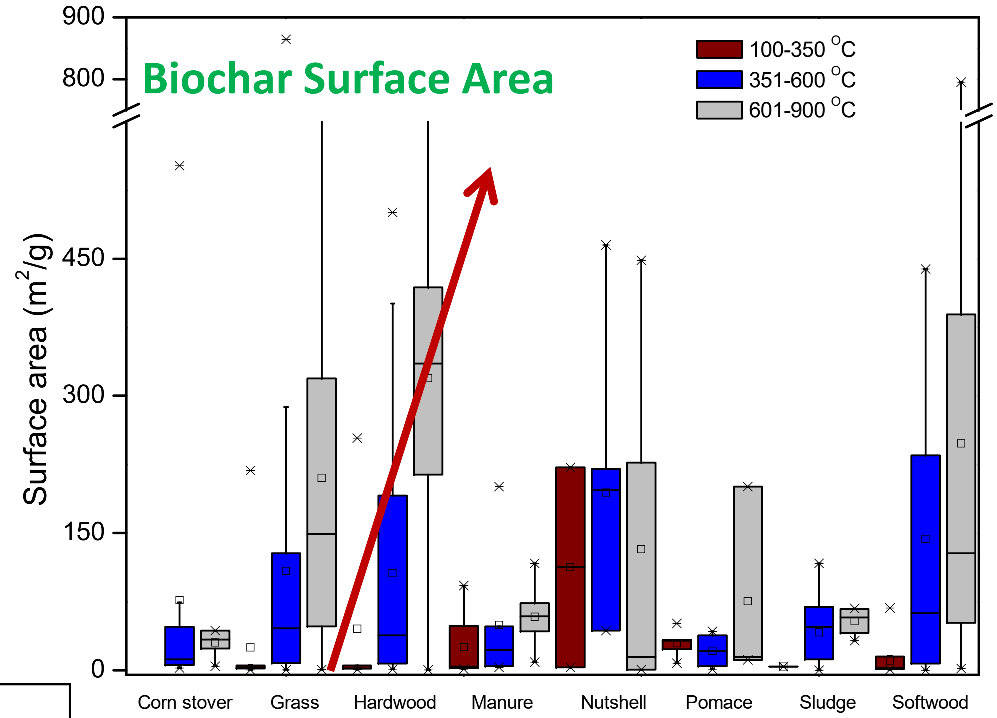


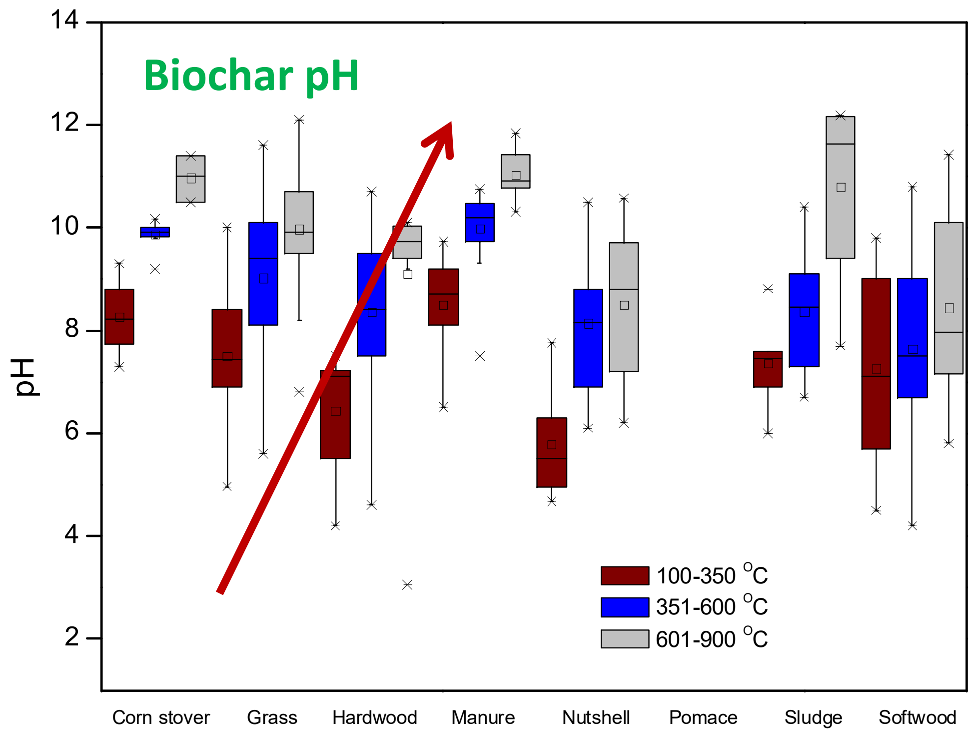
Feedstock Impacts



Data from The UC Davis Biochar Database: biochar.ucdavis.edu

Production Temperature Impacts



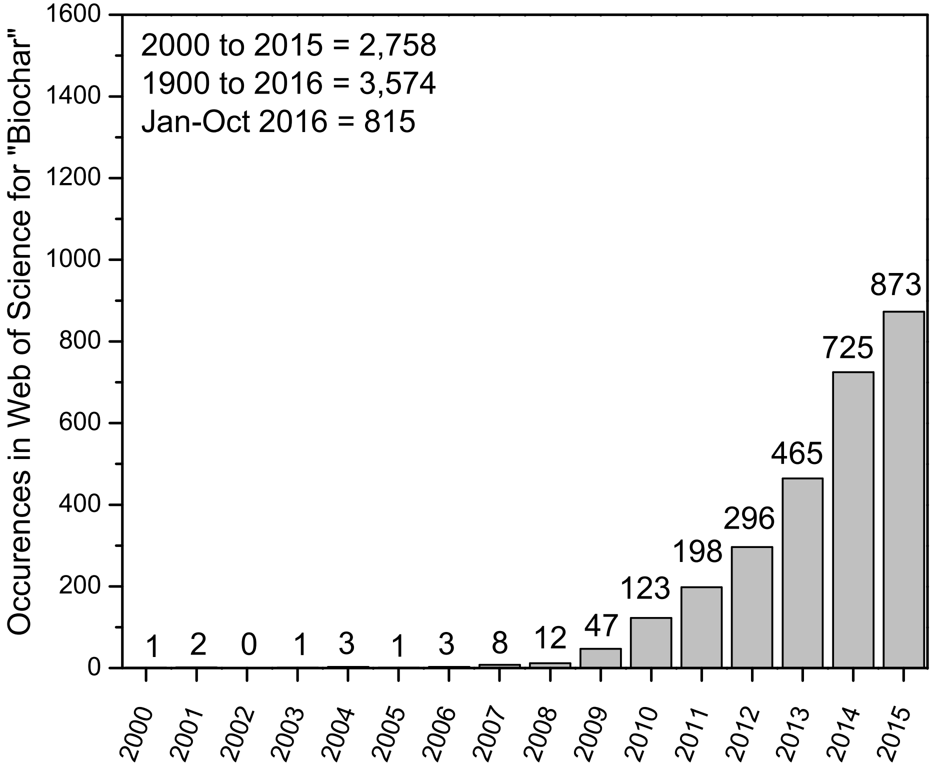


Data from The UC Davis Biochar Database: biochar.ucdavis.edu

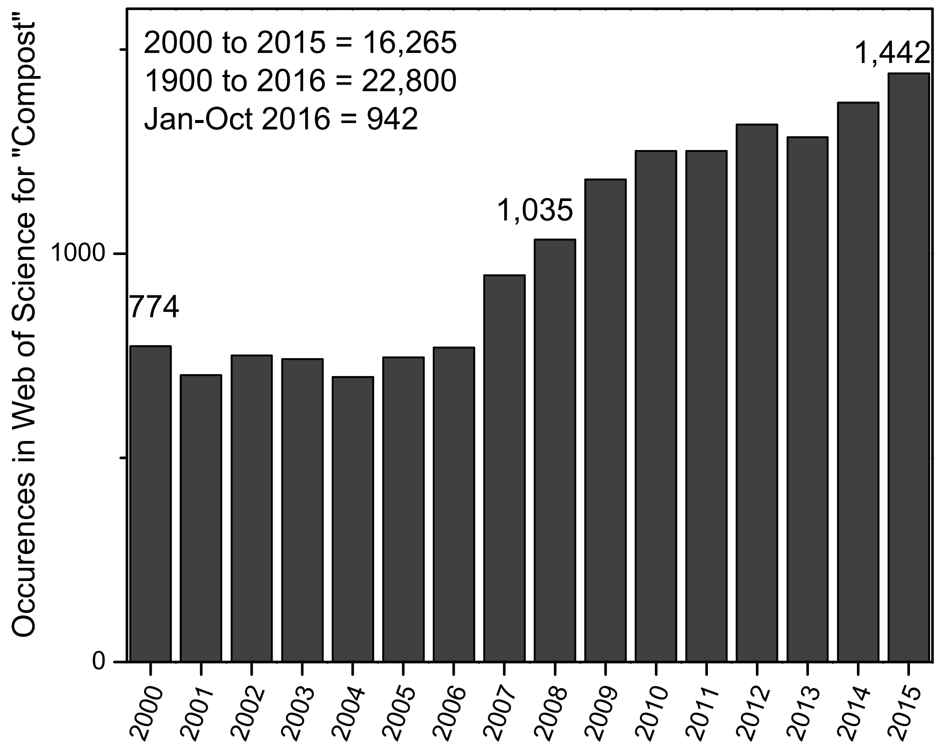
The Biochar Frontier

- **Results from Web of Science Core Collection - Queries on Topic Keyword:**

"Biochar"

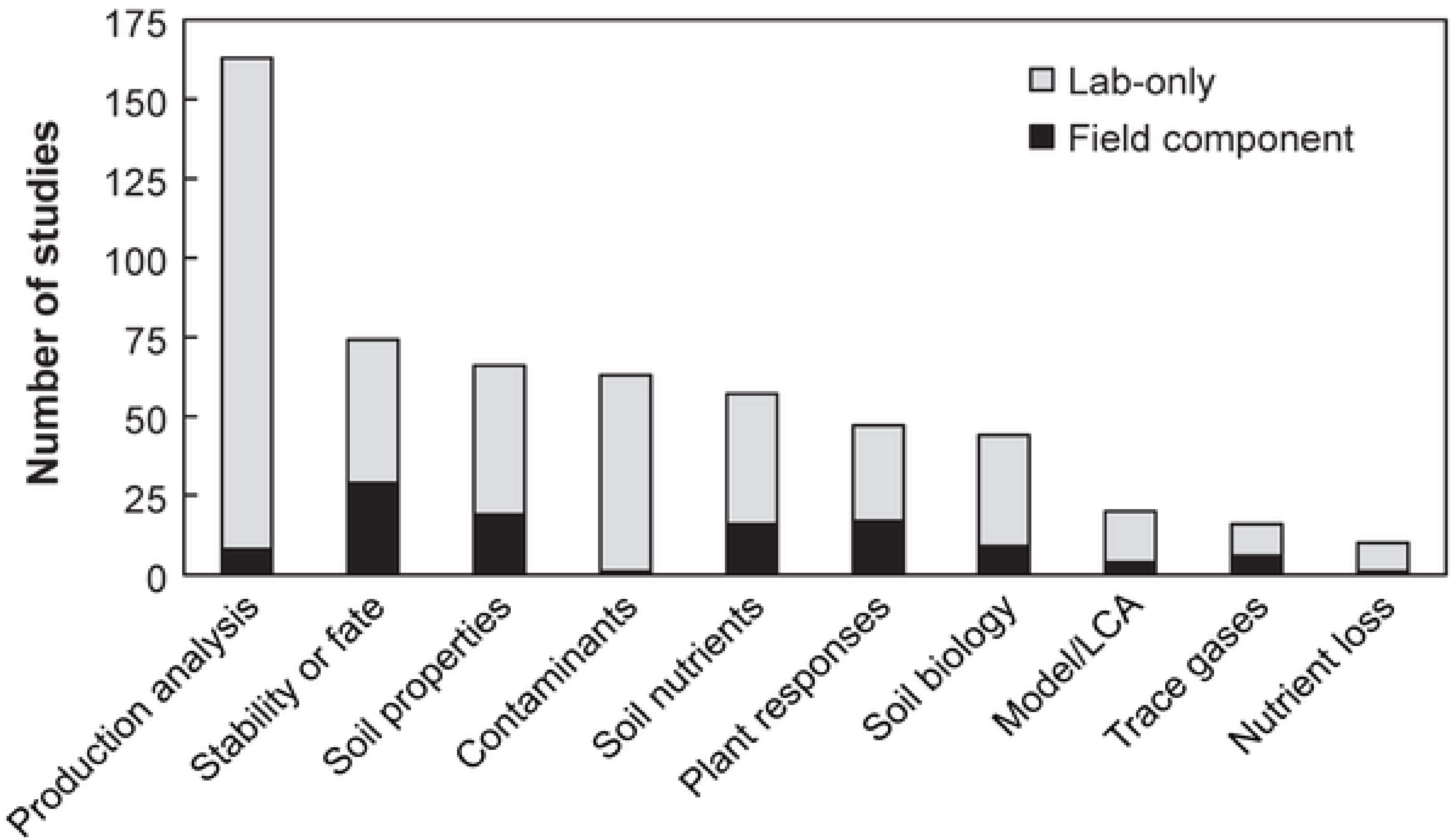


"Compost"



Occurrences of search terms in results are approximate and dependent on institutions subscriptions. These results gathered on searches for each year, accessed through UC Davis (10/10/2016).

Number of research articles addressing specific biochar topic areas



Gurwick NP, Moore LA, Kelly C, Elias P (2013) A Systematic Review of Biochar Research, with a Focus on Its Stability in situ and Its Promise as a Climate Mitigation Strategy. PLoS ONE 8(9): e75932. doi:10.1371/journal.pone.0075932

Journal of Environmental Quality SPECIAL SECTION

2012 ENVIRONMENTAL BENEFITS OF BIOCHAR

Biochar: A Synthesis of Its Agronomic Impact beyond Carbon Sequestration

Kurt A. Spokas,* Keri B. Cantrell, Jeffrey M. Novak, David W. Archer, James A. Ippolito, Harold P. Collins, Akwasi A. Boateng, Isabel M. Lima, Marshall C. Lamb, Andrew J. McAloon, Rodrick D. Lentz, and Kristine A. Nichols

---

"Biochar is not a single entity but rather spans a wide range of black carbon forms."

- **50% of studies show yield increases with biochar** (or black carbon)
  → *50% report decreases or no significant decreases*

- Agronomic benefits in degraded soils are often emphasized, negligible and negative results not given as much attention.

Biochar does not always provide benefits. We must determine the conditions for biochars, soils, and cropping systems where maximum benefits can be realized for a desired outcome.

Agriculture, Ecosystems and Environment 144 (2011) 175–187

ELSEVIER

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Review

A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis

S. Jeffery[a,*], F.G.A. Verheijen[a,d], M. van der Velde[a,b], A.C. Bastos[c]

Analysis of 16 studies and 177 treatments

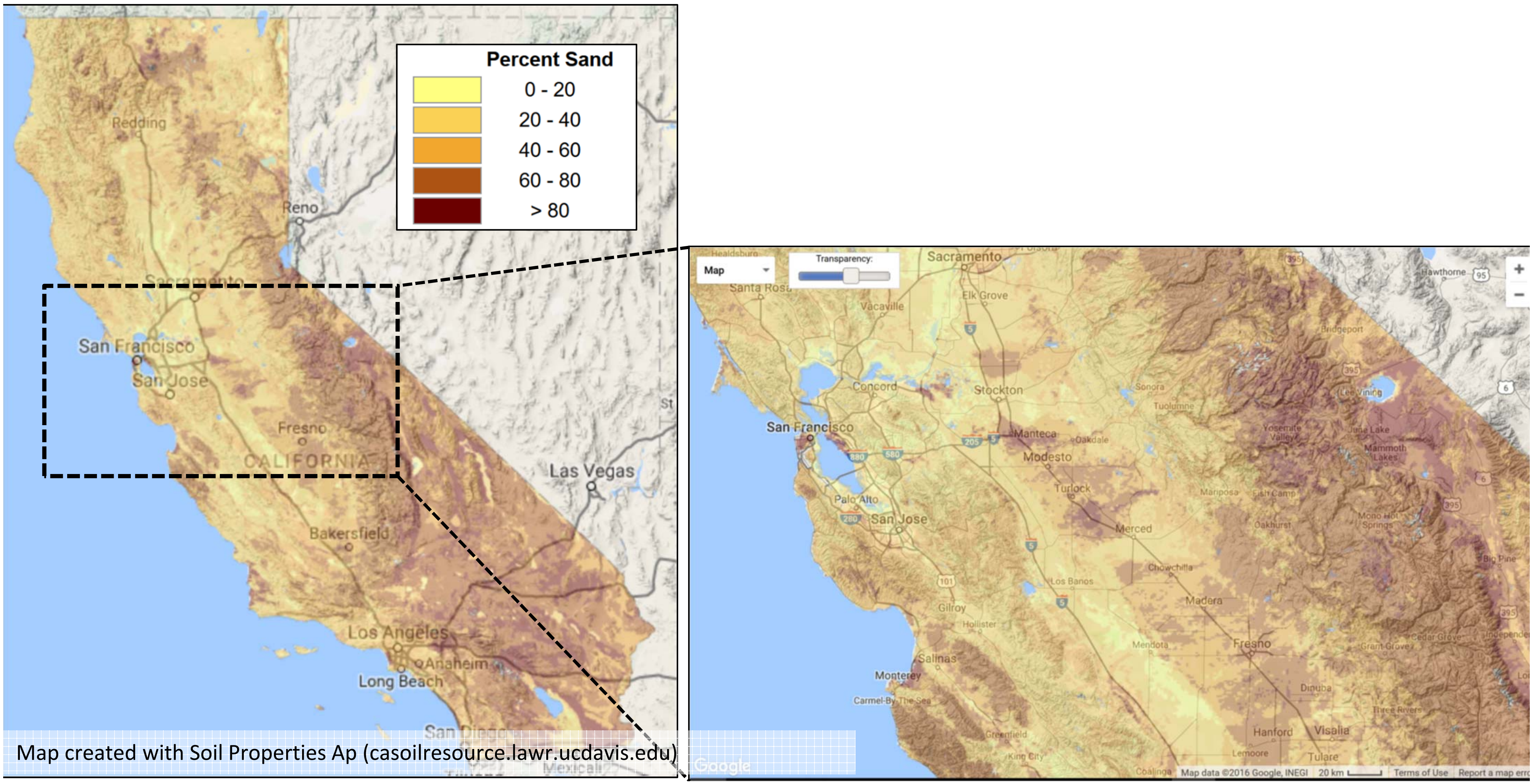
- Small, but significant benefit for crop productivity from biochar added to soil
  - Mean increase of +10% → *benefits observed more then 50% of the time*
  - Range: -28% to +39%
- Greatest benefits:
  - Acidic soils: +14%
  - Neutral soils: +13%
  - Course texture: +10%
  - Medium texture: +13%

Biochar provides benefits when it can impact:
- pH (“liming”), porosity, nutrient availability

- Greatest improvement seen at rate of 100 tons/ha
- Best Performing biochars include: Poultry litter and wood chips
- Biochar performed better in pot vs field trials, and, influenced total biomass more than yield measurements

Biochar use in CA: Soil Texture

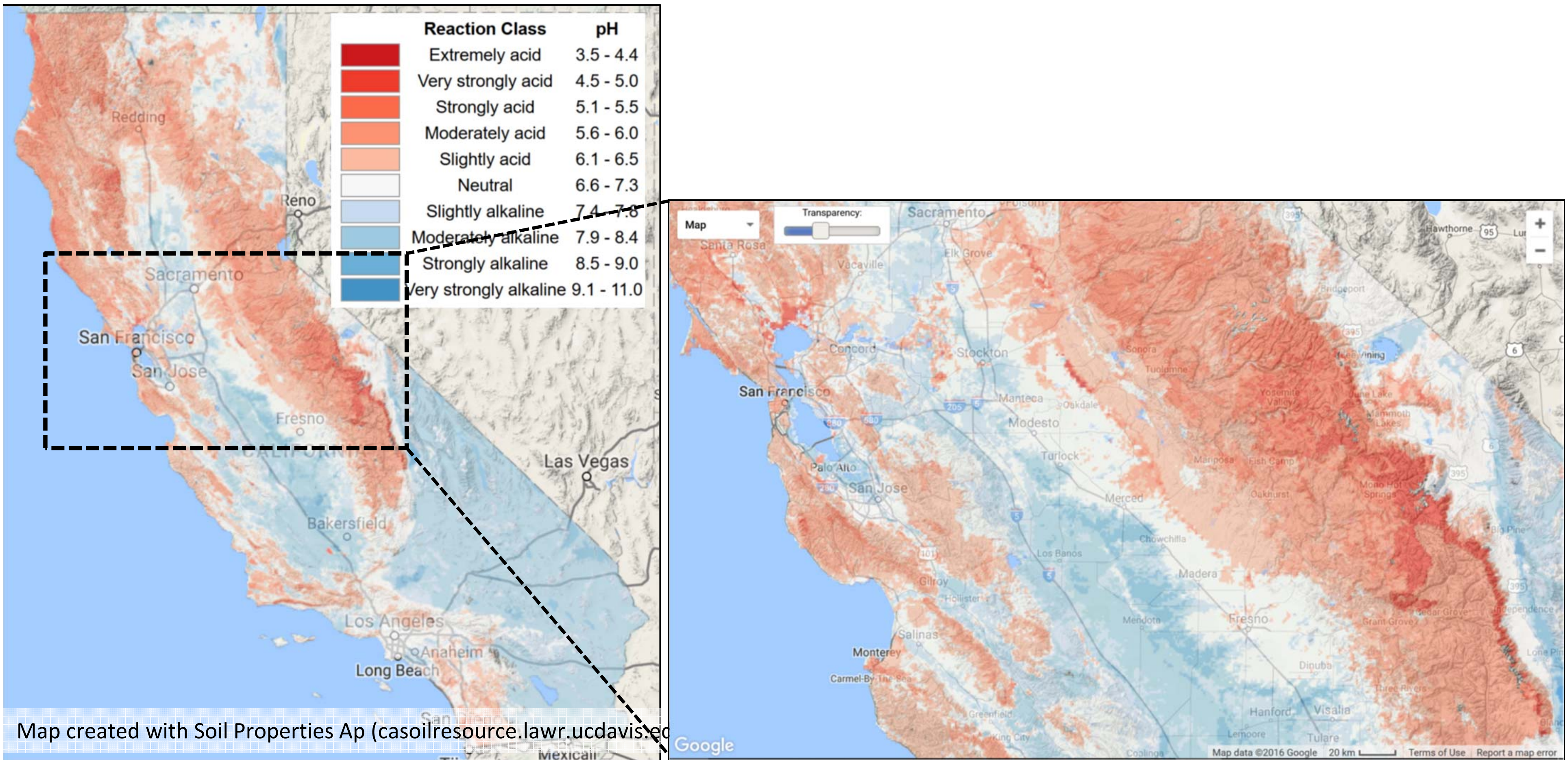
- Biochar application has most potential benefit in coarse textured soils
- Potential to increase porosity, organic C content, and enhance fertility



Map created with Soil Properties Ap (casoilresource.lawr.ucdavis.edu)

Biochar use in CA: Soil pH

- Application of biochars should consider soil pH
- Biochar use in acidic or neutral soils likely to be most beneficial

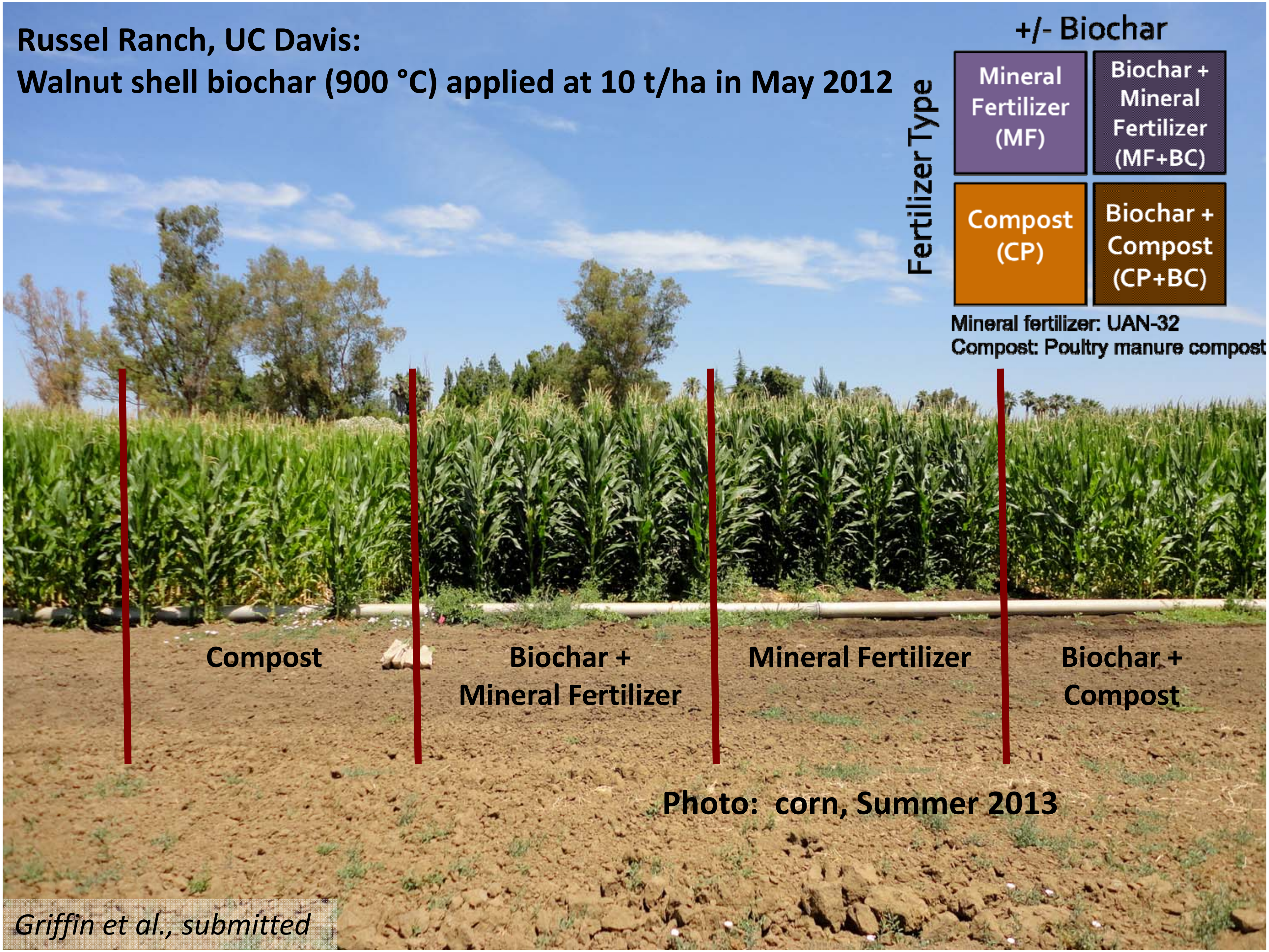


Map created with Soil Properties Ap (casoilresource.lawr.ucdavis.ed

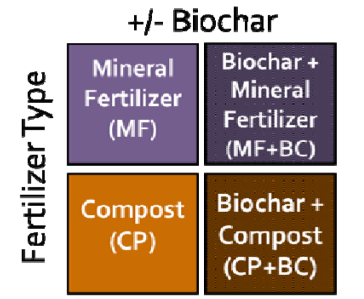
Nutrient Content of Biochar

Adapted from Spokas et al. 2012

Feedstock	Temperature °C	pH	Fertilizer equivalent ratio (kg/ton biocar)			Reference
			N	P	K	
Hardwood	450-600	5.7	3	0.3	6	Novak et al. 2009
Softwood (pine)	465	6.1	3	0.8	4	Novak et al. 2009
Corn stover	500	n/a	16	3	12	Brewer et al. 2009
Leaves (*E.saligna*)	550	11.8	17	3	15	Singh et al. 2010
Cow manure	550	8.9	11	5	23	Singh et al. 2010
Swine manure	350	8.2	37	39	18	Cantrell & Martin 2011
	700	8.2	26	59	26	
Poultry litter	350	8.7	50	30	60	Novak et al. 2009
	700	10.3	30	40	90	

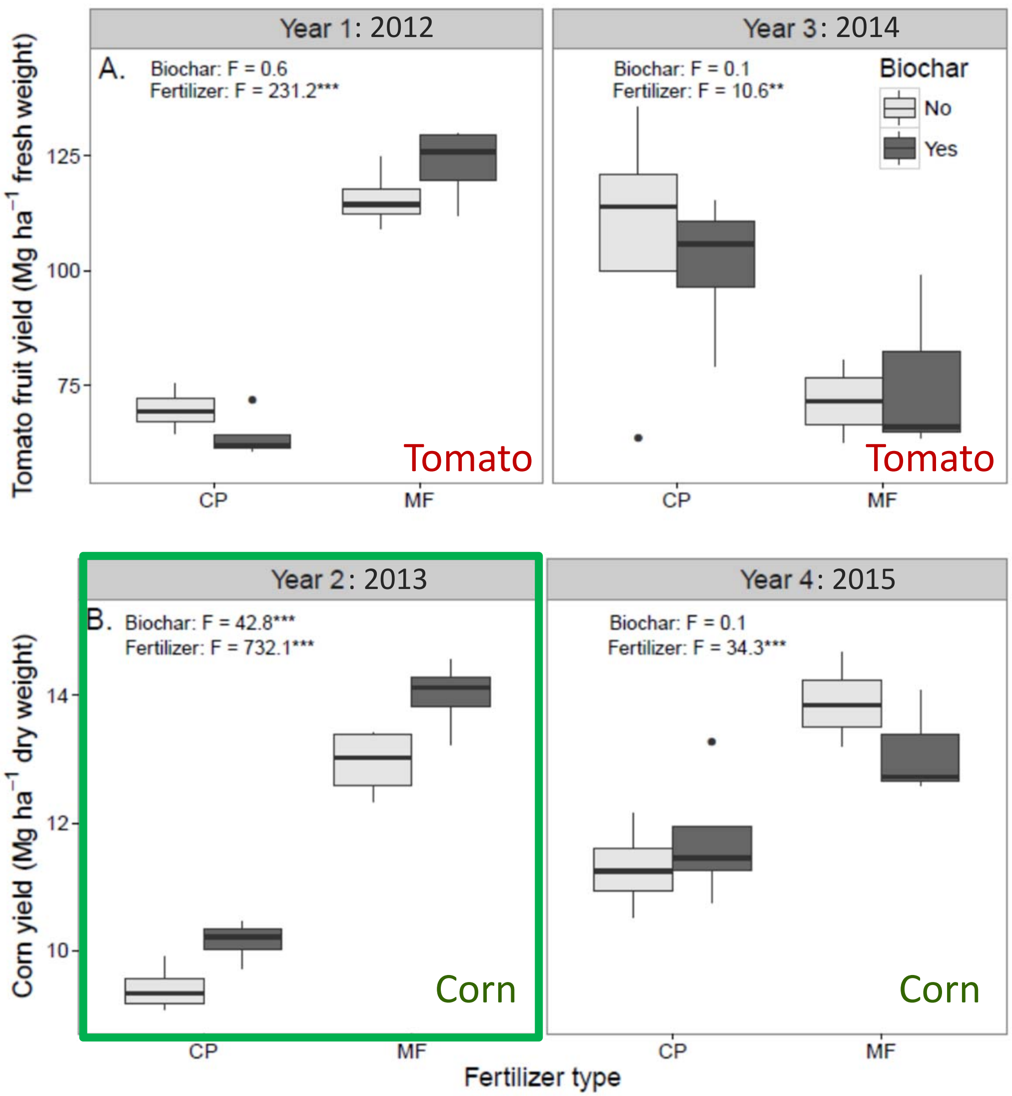

Russel Ranch, UC Davis:
Walnut shell biochar (900 °C) applied at 10 t/ha in May 2012
+/- Biochar
Fertilizer Type
Mineral Fertilizer (MF)
Biochar + Mineral Fertilizer (MF+BC)
Compost (CP)
Biochar + Compost (CP+BC)
Mineral fertilizer: UAN-32
Compost: Poultry manure compost
Compost
Biochar + Mineral Fertilizer
Mineral Fertilizer
Biochar + Compost
Photo: corn, Summer 2013
Griffin et al., submitted

Russel Ranch, UC Davis:
Walnut shell biochar (900 °C) applied at 10 t/ha in May 2012

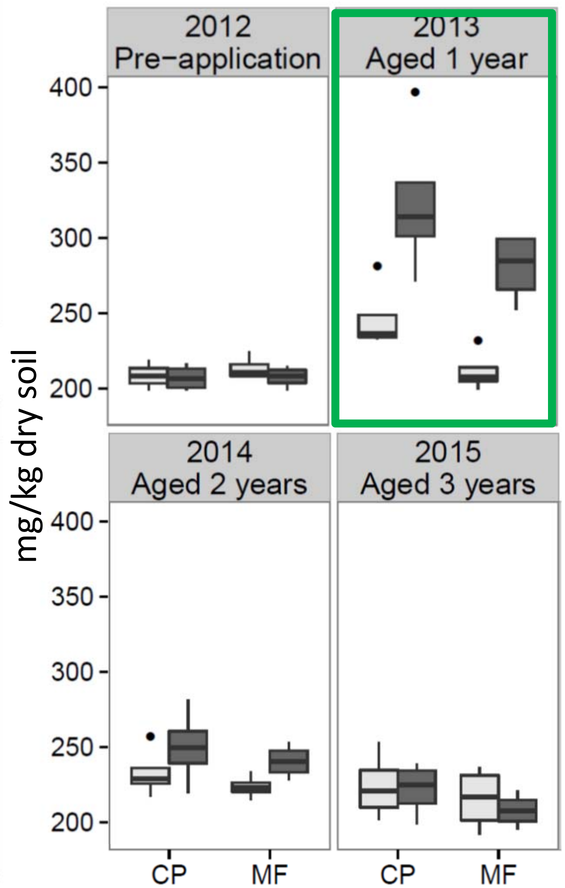


Mineral fertilizer: UAN-32
Compost: Poultry manure compost

Crop Yield after Biochar Application



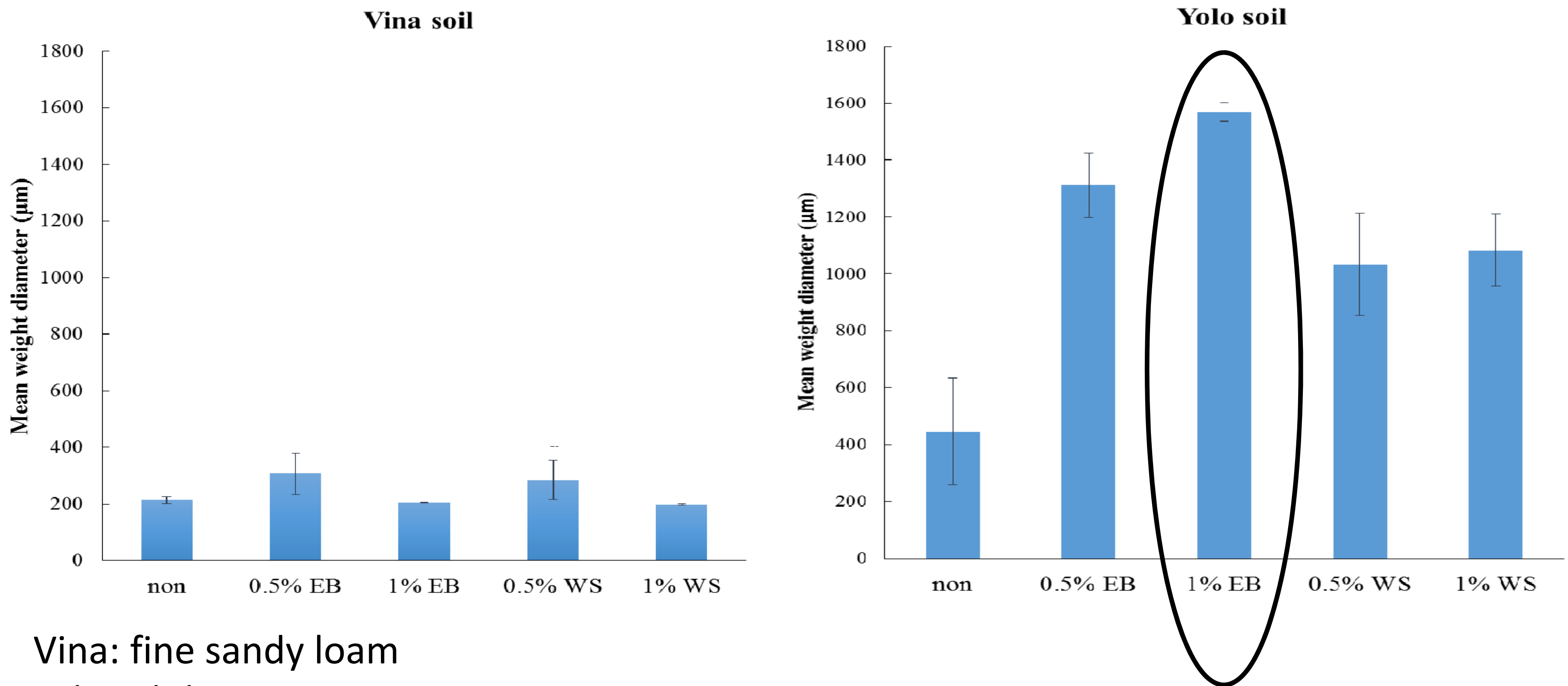
Soil: Extractable K^+



- 1 year aging of biochar provided nutrients and increased crop yield in year 2
- Short-term increases in K^+, Ca^{2+} and PO_4-P

Griffin et al., submitted

Impact of biochar and soil type on soil aggregation



- Vina: fine sandy loam
- Yolo: silt loam
- 60 week incubations: 80% water holding capacity, 23 ± 1 °C

Biochar Source Material	Temp (°C)	Ash (wt %)	Surf. Area (m^2/g)	C (wt %)	C:N	H (wt %)	O (wt %)	pH_w (1:2)	CEC[a] (cmol/kg)
WS: Walnut shell	900	40	227	55	118	0.9	1.6	9.7	33
EB: Softwood + algal digestate	600-700	6.4	2.00	58	142	4.2	32	6.8	67

Data: D. Wang, S. Fonte, S.J. Parikh, F.N.D. Mukome, J. Six, and K.M. Scow – in preparation

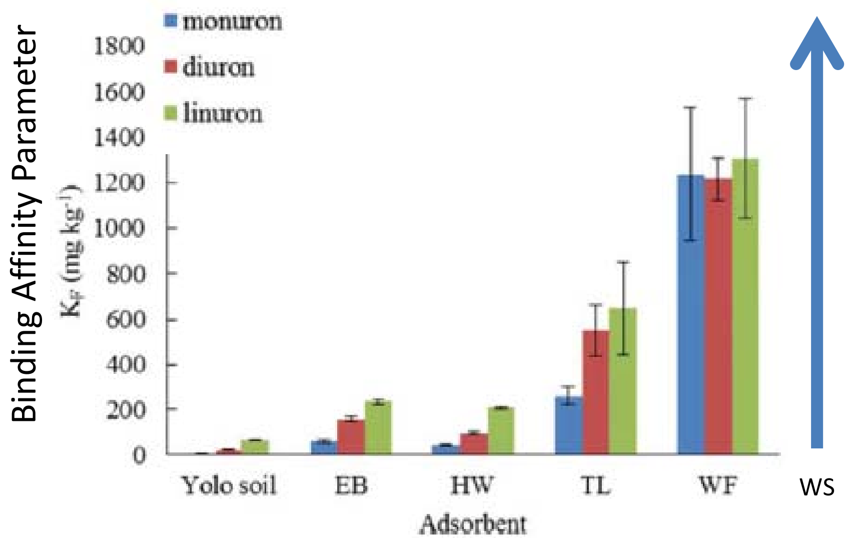
Binding of Organic Chemicals and Metals

Potential impacts on pesticide efficacy

- Sorption of organic agrochemicals
- Different affinities of phenylurea herbicides for biochars:

walnut shell biochar binding > soft wood > turkey litter > hog waste > wood/algal digest.

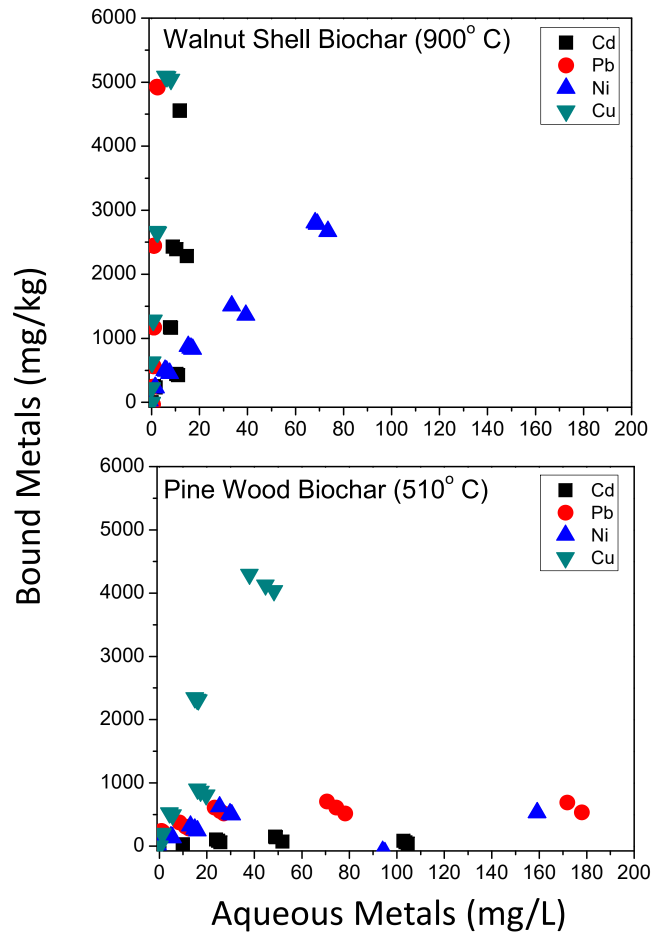
Binding constant (K_F) of biochars and soil for selected herbicides



Data from Wang et al. J. Environ. Sci. Health, B, 2015

Reducing Heavy Metal Bioavailability

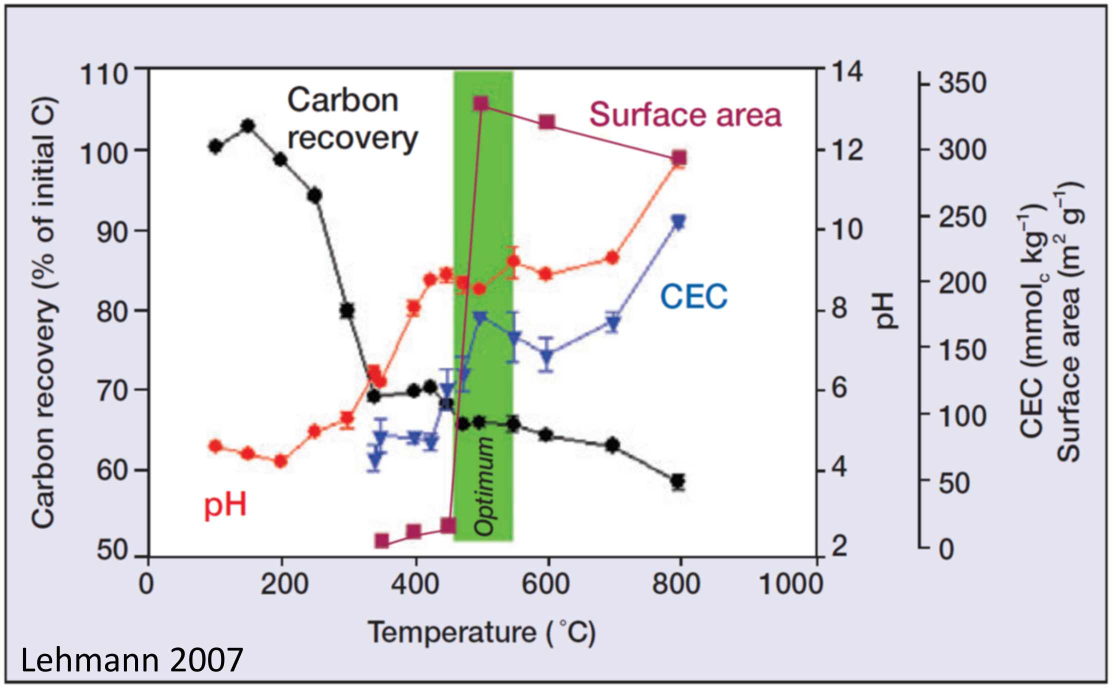
- Not all biochars perform the same.
- The walnut shell biochar binds more metals than the pine wood biochar



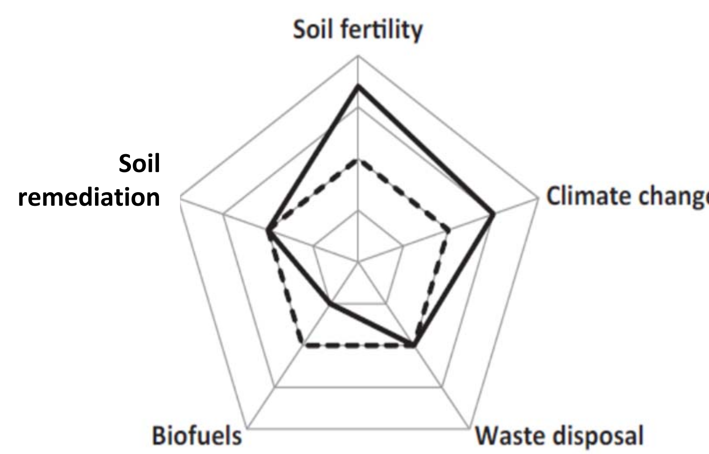
Data from: Bair et al JEQ, 2016

Optimizing Biochar

- Biochar can be created for an intended use → nutrient retention, liming agent, soil remediation, carbon sequestration, bioenergy
- Feedstock and production parameters can be varied to for optimal performance



Lehmann 2007



Jeffrey et al. 2015

Biochar produced from Black Locust (*Robina pseudacacia*)

http://texastreeid.tamu.edu/content/TreeDetails/?id=112

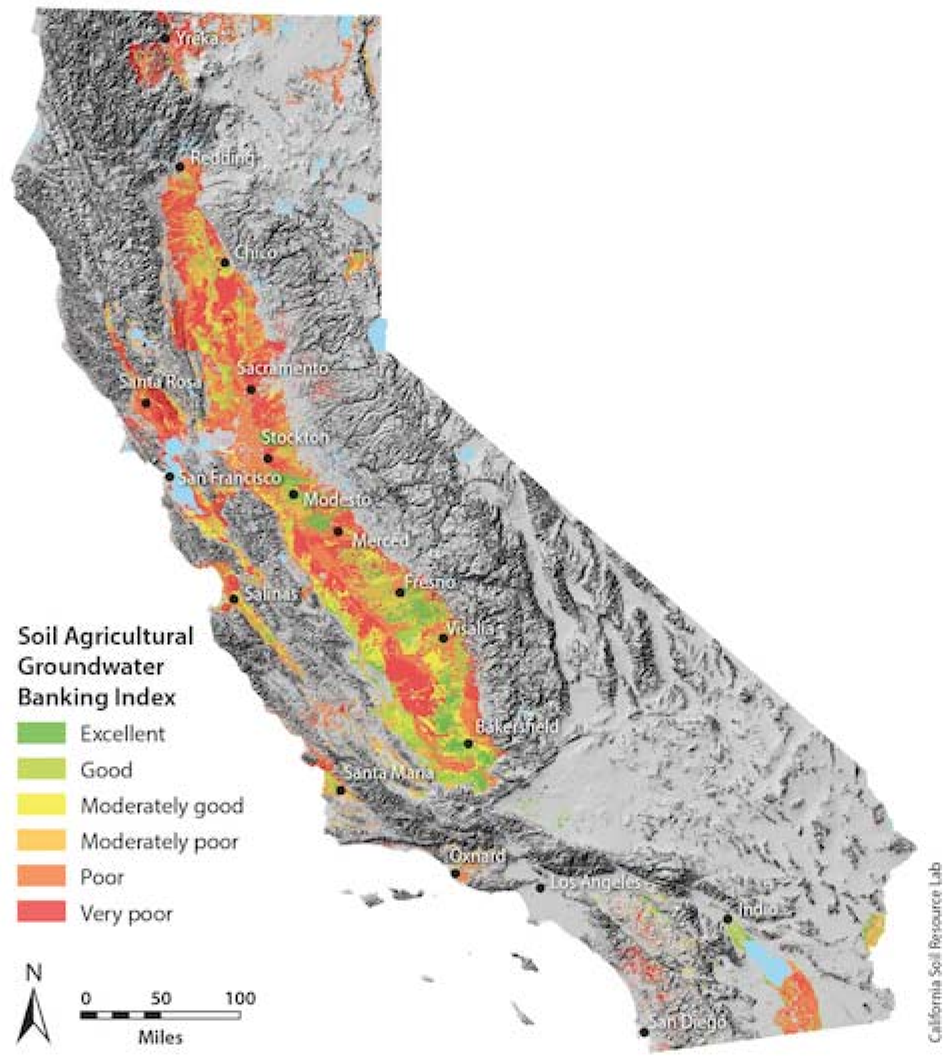
- A single biochar is unlikely to be the ideal materal for many different intended outcomes

Exploring The Biochar Frontier

- Moving Forward with Biochar
  - More research (field) required to confirm current observations (lab)
  - Conducting long-term experiments
  - Optimizing biochar for specific climate-soil-plant-cropping systems
  - Optimizing application rates
  - Examining nutrient use efficiency and leaching
  - Elucidating physical, chemical, and biological mechanisms

Goal → Map matching benefits/utility with biochar material, soil type, cropping system and climate – with strong rationale and understanding of soil processes

Example: Map showing agricultural soils suitability for groundwater banking.



O'Geen et al. California Agriculture, 69:75-84.

Acknowledgements

Collaborators:

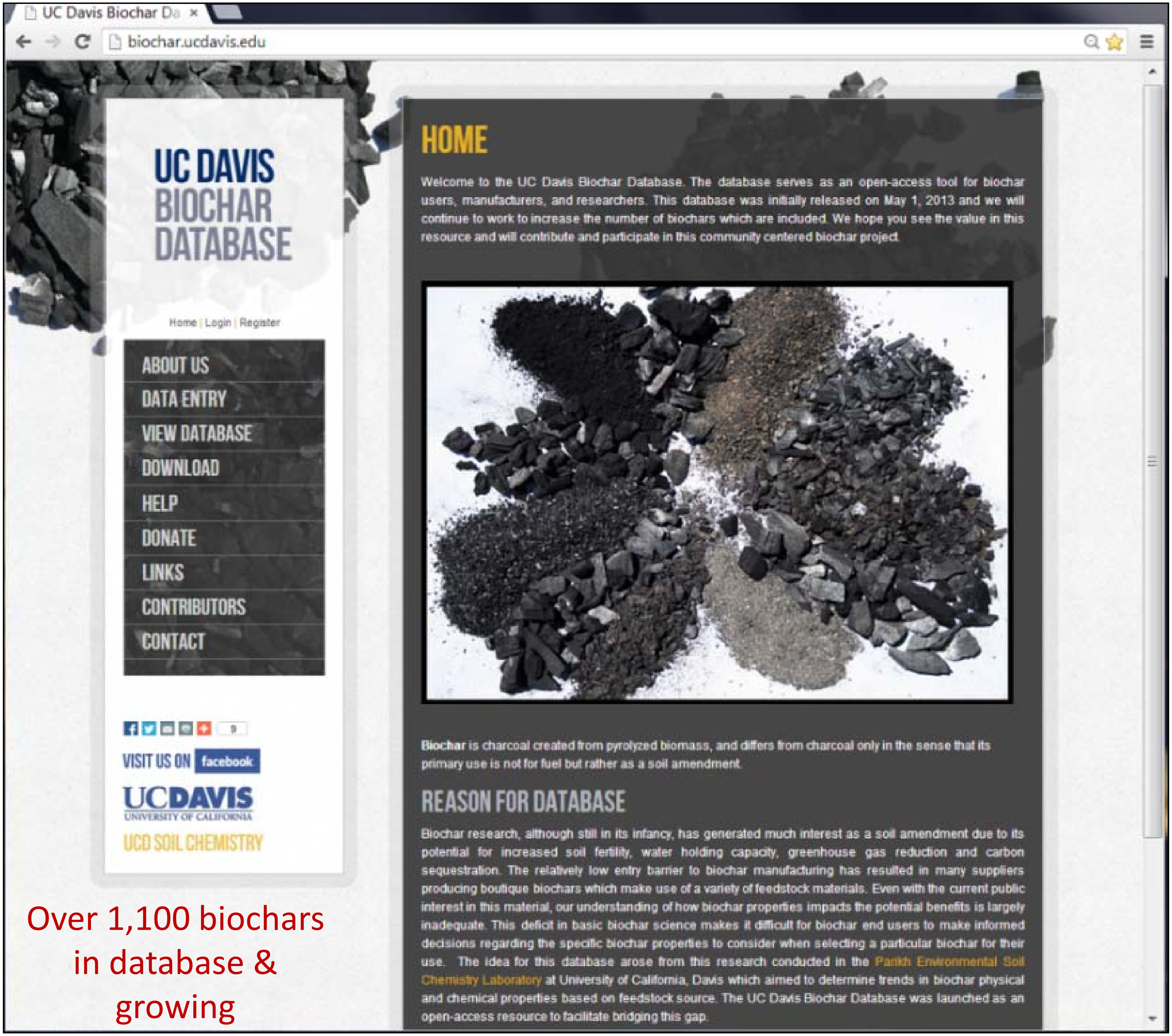
- Fungai Mukome, William Jessup Univ.
- Daoyuan Wang, UC Davis
- Kate Scow, UC Davis
- Steve Fonte, Colorado State Univ.
- Johan Six, ETH Zurich
- Deirdre Griffin, UC Davis
- Daniel Bair, UC Davis
- Sarah Hafner, UC Davis
- Ina Popova, Univ. of Idaho

Environmental Soil Chemistry, UC Davis

Funding

- UC Davis Agriculture Sustainability Institute through a grant form the David and Lucille Packard Foundation
- USDA-NIFA Grant #2012-67009-20070
- California Energy Commission Grant #500-09-035

biochar.ucdavis.edu



Over 1,100 biochars in database & growing

References

- Bair, D. A., F. N. D. Mukome, I. E. Popova, T. A. Ogunyoku, A. Jefferson, D. Wang, S. C. Hafner, T. M. Young and S. J. Parikh (2016). "Sorption of Pharmaceuticals, Heavy Metals, and Herbicides to Biochar in the Presence of Biosolids." Journal of Environmental Quality.
- Brewer, C. E., K. Schmidt-Rohr, J. A. Satrio and R. C. Brown (2009). "Characterization of Biochar from Fast Pyrolysis and Gasification Systems." Environmental Progress & Sustainable Energy **28**(3): 386-396.
- Cantrell, K. B. and J. H. Martin (2012). "Stochastic state-space temperature regulation of biochar production. Part II: Application to manure processing via pyrolysis." Journal of the Science of Food and Agriculture **92**(3): 490-495.
- Jeffery, S., F. G. A. Verheijen, M. van der Velde and A. C. Bastos (2011). "A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis." Agriculture Ecosystems & Environment **144**(1): 175-187.
- Mukome, F. N. D. and S. J. Parikh (2015). Chemical, Physical, and Surface Characterization of Biochar. Biochar: Production, Characterization, and Applications. Y.-S. Ok, S. M. Uchimiya, S. X. Chang and N. Bolan. Boca Raton, FL, CRC Press.
- Mukome, F. N. D., J. Six and S. J. Parikh (2013). "The effects of walnut shell and wood feedstock biochar amendments on greenhouse gas emissions from a fertile soil." Geoderma **200–201**(0): 90-98.
- Mukome, F. N. D., X. Zhang, L. C. R. Sillva, J. Six and S. J. Parikh (2013). "Use of chemical and physical characteristics to investigate trends in biochar feedstocks." Journal of Agricultural and Food Chemistry **61**(9): 2196-2204.
- Novak, J. M., I. Lima, X. B., J. W. Gaskin, C. Steiner, K. C. Das, M. Ahmedna, D. Rehrah, D. W. Watts, W. J. Busscher and H. Schmobert (2009). "Characterization of designer biochars produced at different temperatures and their effects on a lomay sand." Annals of Environmental Science **3**: 195-206.
- O'Geen, A. T., M. B. B. Saal, H. E. Dahlke, D. A. Doll, R. B. Elkins, A. Fulton, G. E. Fogg, T. Harter, J. W. Hopmans, C. Ingels, F. J. Niederholzer, S. Sandoval Solis, P. S. Verdegaal and M. Walkinshaw (2015). "Soil suitability index identifies potential areas for groundwater banking on agricultural lands." California Agriculture **69**(2): 75-84.
- Singh, B., B. P. Singh and A. L. Cowie (2010). "Characterisation and evaluation of biochars for their application as a soil amendment." Soil Research **48**(7): 516-525.
- Spokas, K. A., K. B. Cantrell, J. M. Novak, D. W. Archer, J. A. Ippolito, H. P. Collins, A. A. Boateng, I. M. Lima, M. C. Lamb, A. J. McAloon, R. D. Lentz and K. A. Nichols (2012). "Biochar: A Synthesis of Its Agronomic Impact beyond Carbon Sequestration." Journal of Environmental Quality **41**(4): 973-989.
- Wang, D., D. E. Griffin, S. J. Parikh and K. M. Scow (2016). "Impact of biochar amendment on soil water soluble carbon in the context of extreme hydrological events." Chemosphere **160**: 287-292.
- Wang, D., F. N. D. Mukome, D. Yan, H. Wang, K. M. Scow and S. J. Parikh (2015). "Phenylurea herbicide sorption to biochars and agricultural soil." Journal of Environmental Science and Health Part B-Pesticides Food Contaminants and Agricultural Wastes **50**(8): 544-551.