GOVERNOR'S OFFICE OF PLANNING AND RESEARCH
STATE OF CALIFORNIA

Biochar for Environmental Management in California

Western Statewide Wood Energy Team Forum

November 15, 2017

Uses of Biochar

As a Soil Amendment

- Carbon Sequestration
- Increase Drought Resiliency
- Enhance Soil Fertility
- Improve Nutrient Use Efficiency/Reduce Nutrient Leaching
- Improve Crop Yields and Quality
- Increase Soil pH (in acidic soils)
- Conduct Remediation at Brown Field/Super Fund Sites

As a Filtration Medium (GAC)

- Removes Toxins, Pollutants, and Heavy Metals from Liquids
- Odorous Gas Capture, such as Hydrogen Sulfide (H_2S), in Gas-Phase Filtration Systems
- Storm Water Remediation and Nutrient Run-Off Capture

* Observed benefits from biochar can be **inconsistent**, or even detrimental to crop growth if a char is not properly designed for a particular soil-crop system.

Biochar is Really an Umbrella Term

- Due to the diversity of feedstock material from both the forestry and agricultural sectors, thousands of different biochars can be designed and produced for a particular use.

- “Although there are certain parameters that do make a quality biochar, biochar quality is determined by its intended purpose.”
  – Sanjai Parikh, UC Davis

- “Biochar properties, and *performance*, are a function of feedstock material **AND** production parameters.” – Sanjai Parikh, UC Davis

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

Slide courtesy of Sanjai Parikh, UC Davis

Understanding Carbon Storage in Biochar

Simple Definition

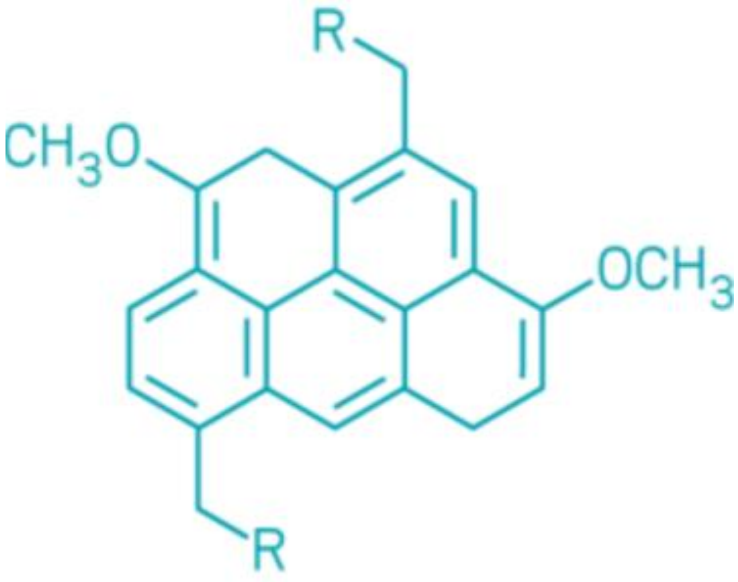
- The energy required by microbes to access the carbon stored in biochar appears to be greater than that acquired when it is released.

- In *contrast*, carbon compounds in the original biomass (feedstock), are a net positive energy source and are more readily mineralized by soil microbes.

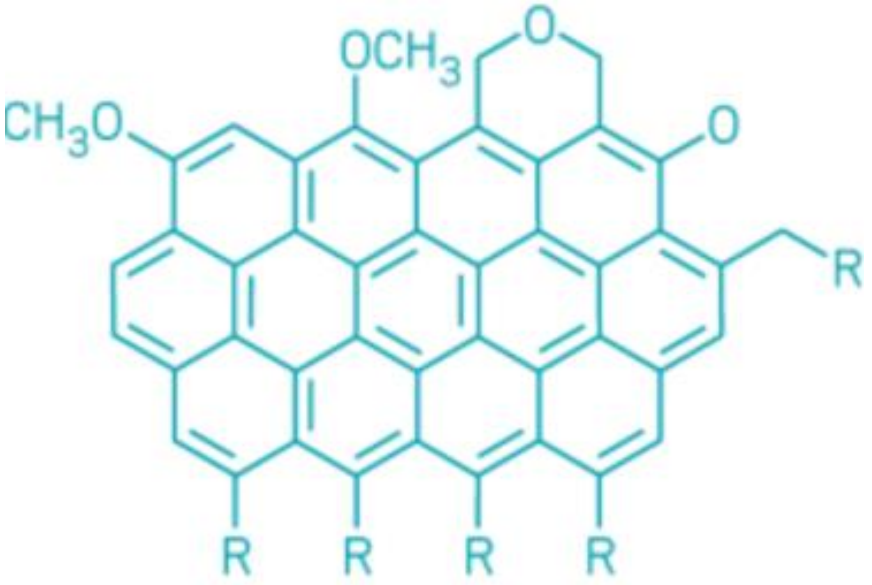
Technical Definition

- The carbon lattice structure made up of fused polyaromatic carbon rings is hypothesized to be the key property that confers a resistance to mineralization (conversion from organic carbon to carbon dioxide via respiration), by soil microbes that utilize organic matter i.e., hydrocarbons, as food (Lehmann et al, 2015).

Higher Temperature Treatment Increases Poly-Aromatic Carbon Ring Structure of Biochar



Corn-350-BC

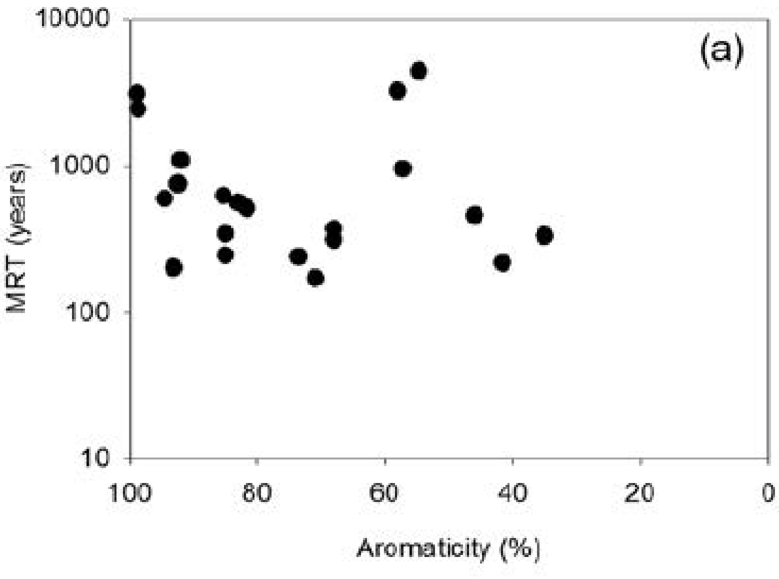


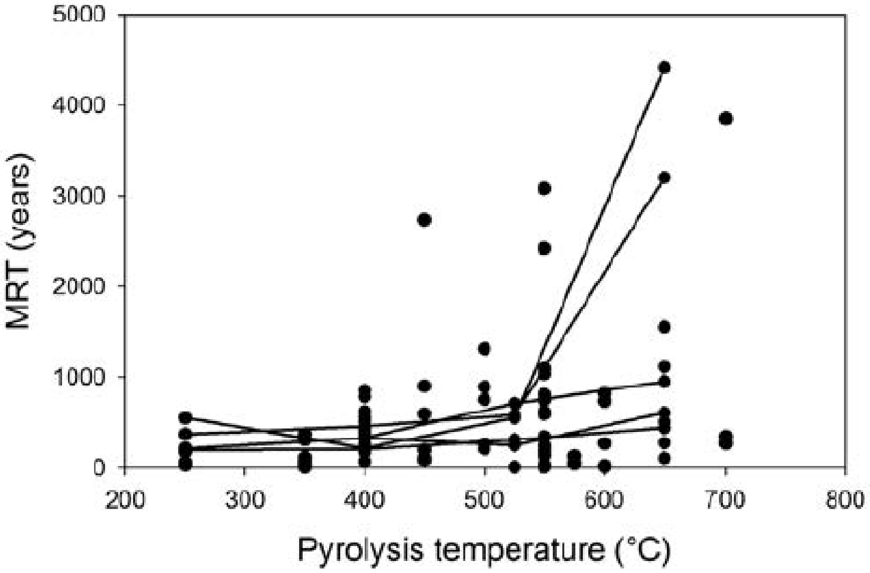
Corn-600-BC

Structures of biochar made from corn at 350 °C (left) and 600 °C (right); R represents unspecified organic groups.

The Links Between Aromaticity, Temperature Treatment and Mean Residence Time

- At higher temperature treatments, MRT increases.
- As aromaticity increases, MRT increases.



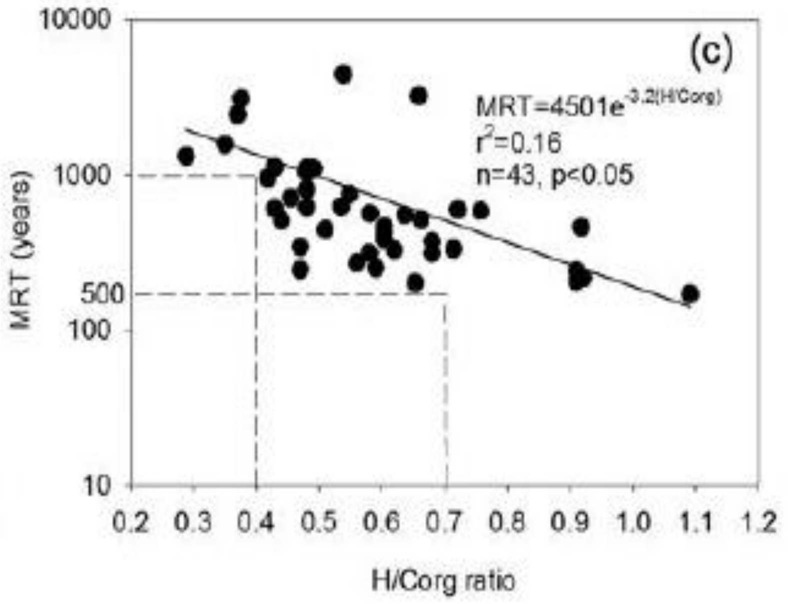


Source: Lehmann et al. (2015), Persistence of Biochar in Soil.

Measuring Biochar Persistence

- “The term **persistence**, a measurable, numerical parameter, e.g. expressed as mean residence time (MRT), is used to characterize the length of time that carbon in biochars remain sequestered in soils.” (Lehmann et al. 2015)

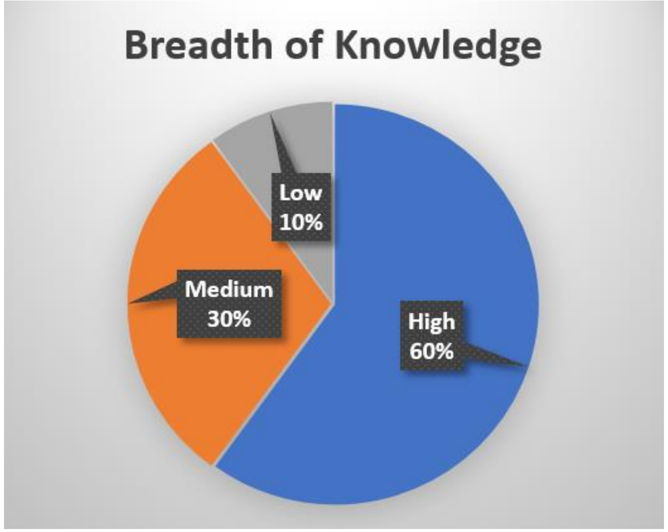
- **Persistence** can be determined by measuring the amount of hydrogen atoms present per carbon atom (H/Corg), embedded within the molecular structure of a given biochar.
    - H/Corg ratio of 0.7 = MRT of 500 years
    - H/Corg ratio of 0.4 = MRT of 1,000 years



This graphic display illustrates the relationship between the Hydrogen to Carbon molar ratio of biochars and the predicted mean residence time (MRT) of those chars. Source: Lehmann et al. (2015), Persistence of Biochar in Soil.

Carbon Sequestration **Research Findings**, OPR Biochar Research Advisory Group

- *What is the capacity for biochar to sequester carbon from biomass?*
  - “The act of pyrolyzing biomass does convert it into more stable C forms. Higher temperature processes will yield more stable biochar, but also have lower yields.”
    – Sanjai Parikh, UC Davis
  - “Biochar, especially high temperature biochars, have a significant component of very stable carbon, that when added to soils will have a residence time on the order of hundreds to thousands of years.”
    – Mark Johnson, US EPA



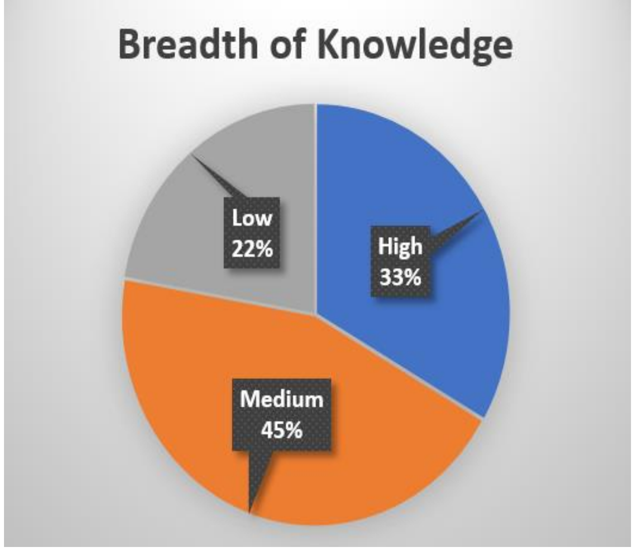
A majority of researchers (6 of 10), who responded to this question, indicated that there is a high breadth of knowledge in this area of interest.

Carbon Sequestration **Research Findings**, OPR Biochar Research Advisory Group

❖ *What is the capacity for biochar to sequester soil carbon?*

- "Biochar has a high affinity for binding soil C, but when considering the factor of scale, the actual amount of C bound to chars might not be significant. The most potential for increasing soil carbon storage would be in sandy soils (least impact in finely textured soils)." – Sanjai Parikh, UC Davis

- "There may be large potential for soil C sequestration with biochar application, but our ability to generalize or quantify C sequestration potential is limited by the number of field studies, incomplete understanding of C stabilization mechanisms, and the wide range of 'types' of biochars."
  – Rebecca Ryals, University of Hawaii



Almost half of the researchers who responded to this question (4 of 9), indicated that there is a medium breadth of knowledge in this area of interest.

Carbon Sequestration **Research Gaps**, OPR Biochar Research Advisory Group

- “Do soils have C sink saturation? What is the residence time of biochar in soils, and how does that vary depending on biochar feedstock, production conditions, and soil types? What are the biological, chemical, and physical mechanisms that stabilize biochar-C, and what conditions make stabilized biochar-C vulnerable to loss?”
  – Rebecca Ryals, University of Hawaii

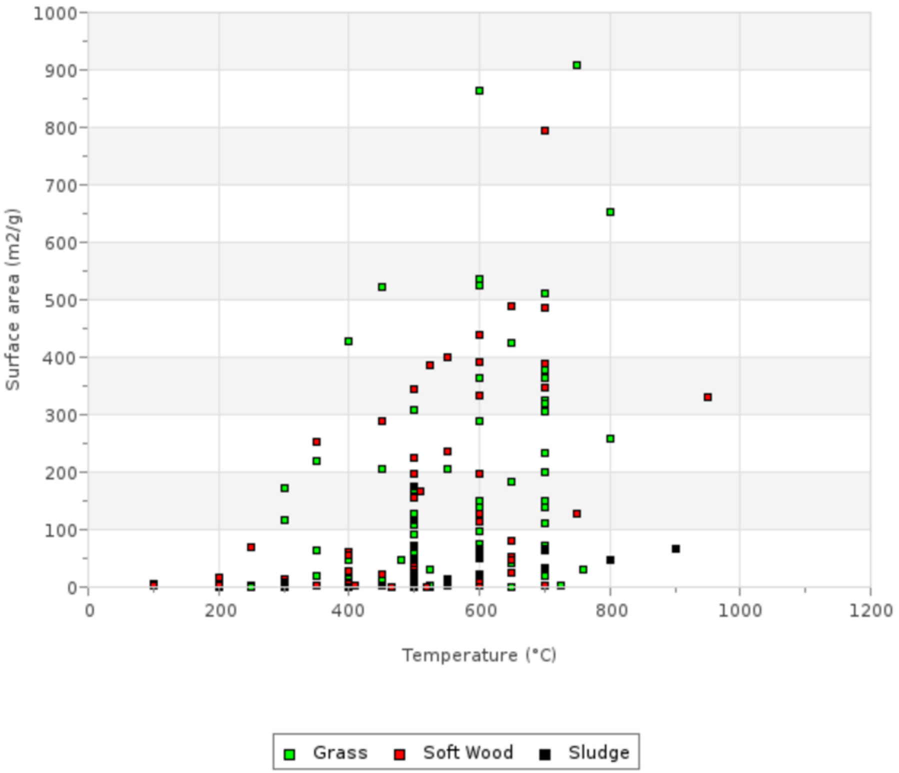
- “Biochar's effect on soil total carbon stocks is pretty clear, but information on how biochar affects soil carbon dynamics (CO2, CH4, and N2O flux), is much less understood.” – Jessica Meisel, Michigan State University

Biochar Impacts on Soil Water Holding Capacity

- **Surface Area** (m^2/gram), is a fundamental property that is generally associated with a soil's water holding capacity (WHC).

- The biomass that biochars are derived from can be modified during the thermochemical conversion process (pyrolysis), to increase surface area correlation at higher temperature treatments (Kim et al., 2012).

- Higher Surface Area = Increase in WHC



Graph courtesy of the UC Davis Biochar Characterization Database. (http://biochar.ucdavis.edu/)

Biochar Characterization Data: Novak et al., 2012

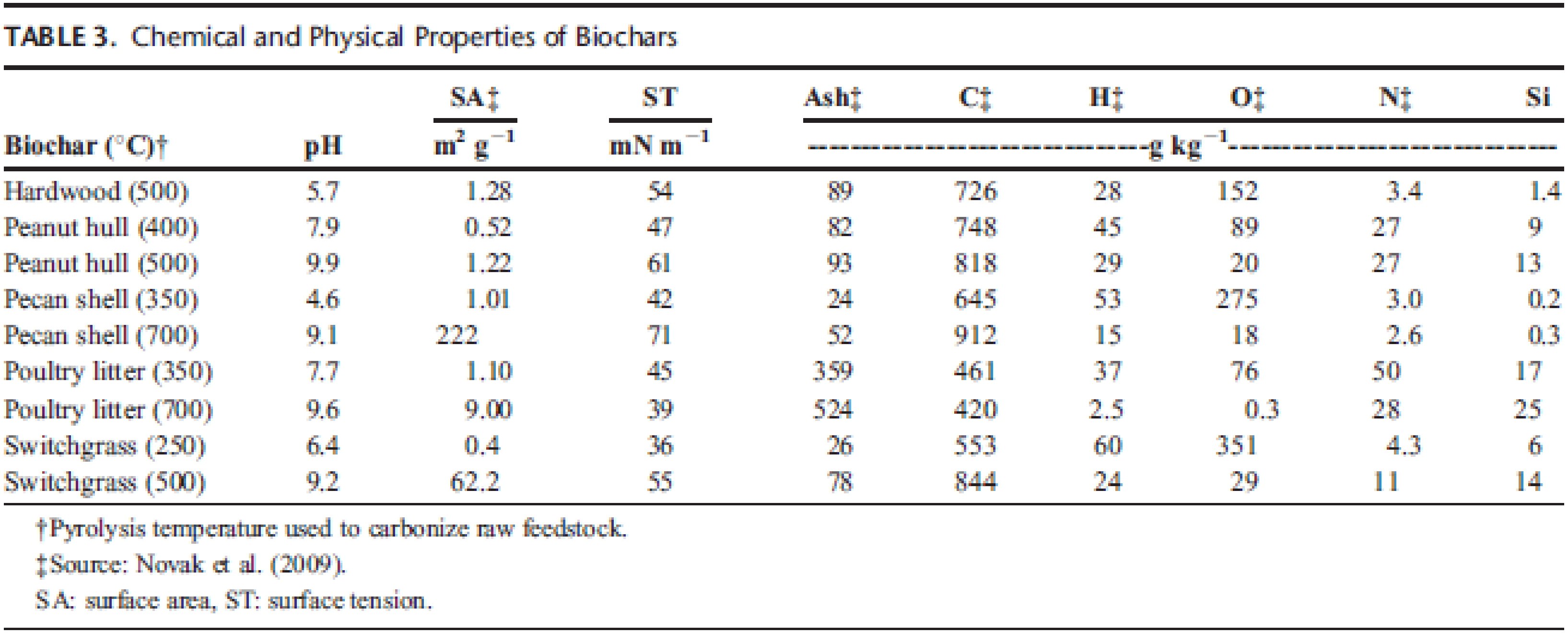


TABLE 3. Chemical and Physical Properties of Biochars

Biochar (°C)†	pH	SA‡	ST	Ash‡	C‡	H‡	O‡	N‡	Si
		$m^2\ g^{-1}$	$mN\ m^{-1}$	------------g kg^{-1}------------					
Hardwood (500)	5.7	1.28	54	89	726	28	152	3.4	1.4
Peanut hull (400)	7.9	0.52	47	82	748	45	89	27	9
Peanut hull (500)	9.9	1.22	61	93	818	29	20	27	13
Pecan shell (350)	4.6	1.01	42	24	645	53	275	3.0	0.2
Pecan shell (700)	9.1	222	71	52	912	15	18	2.6	0.3
Poultry litter (350)	7.7	1.10	45	359	461	37	76	50	17
Poultry litter (700)	9.6	9.00	39	524	420	2.5	0.3	28	25
Switchgrass (250)	6.4	0.4	36	26	553	60	351	4.3	6
Switchgrass (500)	9.2	62.2	55	78	844	24	29	11	14

†Pyrolysis temperature used to carbonize raw feedstock.

‡Source: Novak et al. (2009).

SA: surface area, ST: surface tension.

Soil Moisture Content Data of Biochar Trials: Novak et al., 2012

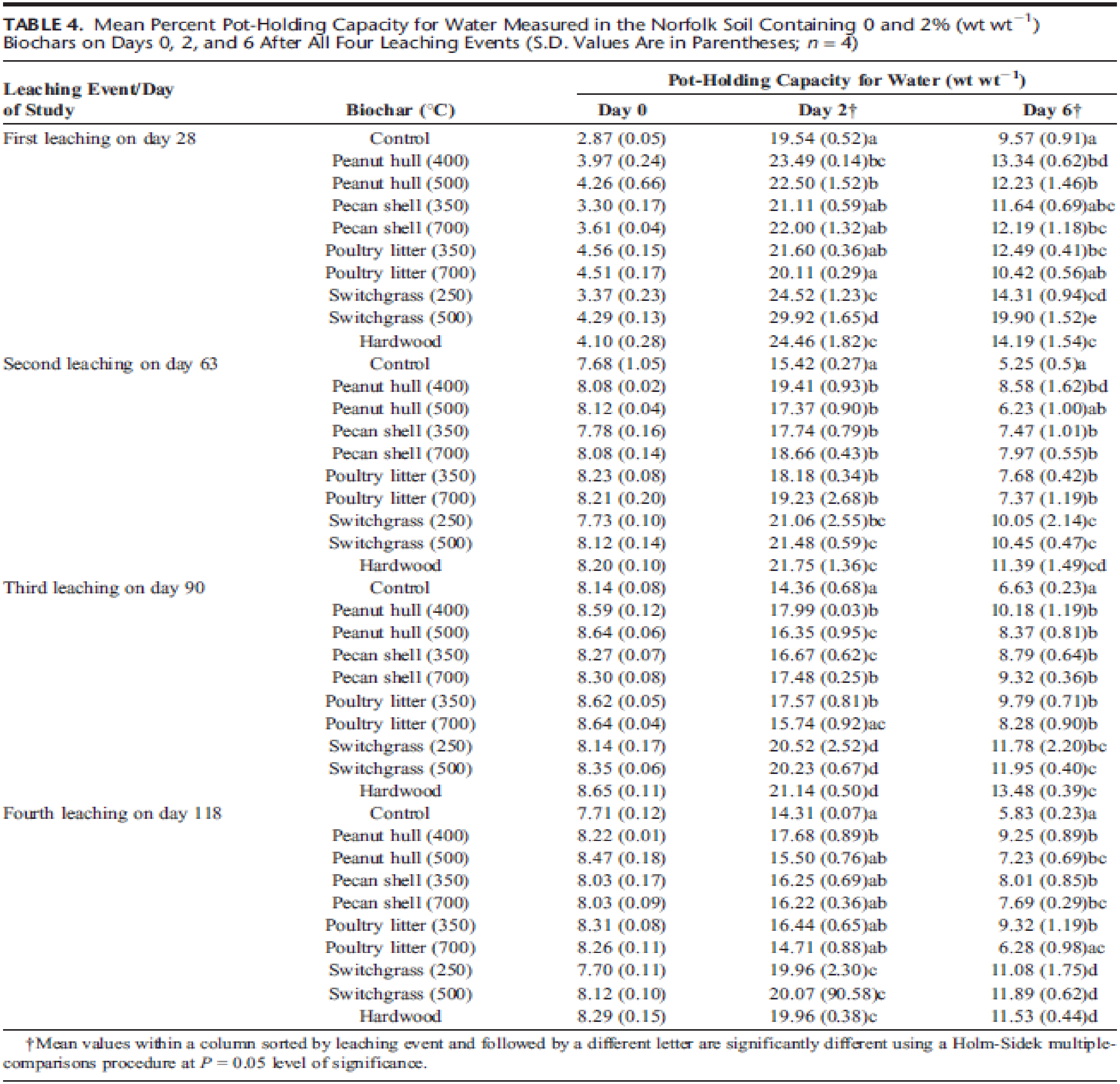


TABLE 4. Mean Percent Pot-Holding Capacity for Water Measured in the Norfolk Soil Containing 0 and 2% (wt wt^{-1}) Biochars on Days 0, 2, and 6 After All Four Leaching Events (S.D. Values Are in Parentheses; $n = 4$)

Leaching Event/Day of Study	Biochar (°C)	Pot-Holding Capacity for Water (wt wt^{-1})		
		Day 0	Day 2†	Day 6†
First leaching on day 28	Control	2.87 (0.05)	19.54 (0.52)a	9.57 (0.91)a
	Peanut hull (400)	3.97 (0.24)	23.49 (0.14)bc	13.34 (0.62)bd
	Peanut hull (500)	4.26 (0.66)	22.50 (1.52)b	12.23 (1.46)b
	Pecan shell (350)	3.30 (0.17)	21.11 (0.59)ab	11.64 (0.69)abc
	Pecan shell (700)	3.61 (0.04)	22.00 (1.32)ab	12.19 (1.18)bc
	Poultry litter (350)	4.56 (0.15)	21.60 (0.36)ab	12.49 (0.41)bc
	Poultry litter (700)	4.51 (0.17)	20.11 (0.29)a	10.42 (0.56)ab
	Switchgrass (250)	3.37 (0.23)	24.52 (1.23)c	14.31 (0.94)cd
	Switchgrass (500)	4.29 (0.13)	29.92 (1.65)d	19.90 (1.52)e
	Hardwood	4.10 (0.28)	24.46 (1.82)c	14.19 (1.54)c
Second leaching on day 63	Control	7.68 (1.05)	15.42 (0.27)a	5.25 (0.5)a
	Peanut hull (400)	8.08 (0.02)	19.41 (0.93)b	8.58 (1.62)bd
	Peanut hull (500)	8.12 (0.04)	17.37 (0.90)b	6.23 (1.00)ab
	Pecan shell (350)	7.78 (0.16)	17.74 (0.79)b	7.47 (1.01)b
	Pecan shell (700)	8.08 (0.14)	18.66 (0.43)b	7.97 (0.55)b
	Poultry litter (350)	8.23 (0.08)	18.18 (0.34)b	7.68 (0.42)b
	Poultry litter (700)	8.21 (0.20)	19.23 (2.68)b	7.37 (1.19)b
	Switchgrass (250)	7.73 (0.10)	21.06 (2.55)bc	10.05 (2.14)c
	Switchgrass (500)	8.12 (0.14)	21.48 (0.59)c	10.45 (0.47)c
	Hardwood	8.20 (0.10)	21.75 (1.36)c	11.39 (1.49)cd
Third leaching on day 90	Control	8.14 (0.08)	14.36 (0.68)a	6.63 (0.23)a
	Peanut hull (400)	8.59 (0.12)	17.99 (0.03)b	10.18 (1.19)b
	Peanut hull (500)	8.64 (0.06)	16.35 (0.95)c	8.37 (0.81)b
	Pecan shell (350)	8.27 (0.07)	16.67 (0.62)c	8.79 (0.64)b
	Pecan shell (700)	8.30 (0.08)	17.48 (0.25)b	9.32 (0.36)b
	Poultry litter (350)	8.62 (0.05)	17.57 (0.81)b	9.79 (0.71)b
	Poultry litter (700)	8.64 (0.04)	15.74 (0.92)ac	8.28 (0.90)b
	Switchgrass (250)	8.14 (0.17)	20.52 (2.52)d	11.78 (2.20)bc
	Switchgrass (500)	8.35 (0.06)	20.23 (0.67)d	11.95 (0.40)c
	Hardwood	8.65 (0.11)	21.14 (0.50)d	13.48 (0.39)c
Fourth leaching on day 118	Control	7.71 (0.12)	14.31 (0.07)a	5.83 (0.23)a
	Peanut hull (400)	8.22 (0.01)	17.68 (0.89)b	9.25 (0.89)b
	Peanut hull (500)	8.47 (0.18)	15.50 (0.76)ab	7.23 (0.69)bc
	Pecan shell (350)	8.03 (0.17)	16.25 (0.69)ab	8.01 (0.85)b
	Pecan shell (700)	8.03 (0.09)	16.22 (0.36)ab	7.69 (0.29)bc
	Poultry litter (350)	8.31 (0.08)	16.44 (0.65)ab	9.32 (1.19)b
	Poultry litter (700)	8.26 (0.11)	14.71 (0.88)ab	6.28 (0.98)ac
	Switchgrass (250)	7.70 (0.11)	19.96 (2.30)c	11.08 (1.75)d
	Switchgrass (500)	8.12 (0.10)	20.07 (90.58)c	11.89 (0.62)d
	Hardwood	8.29 (0.15)	19.96 (0.38)c	11.53 (0.44)d

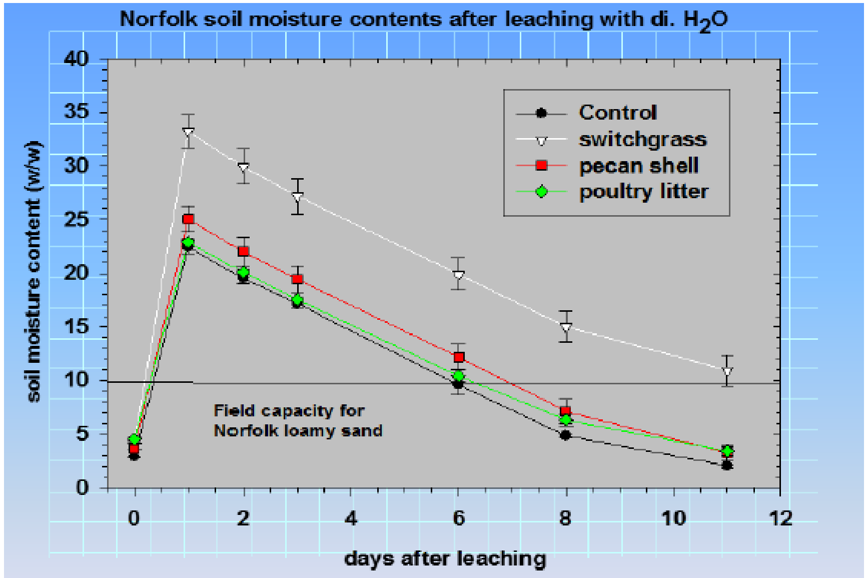
†Mean values within a column sorted by leaching event and followed by a different letter are significantly different using a Holm-Sidek multiple-comparisons procedure at $P = 0.05$ level of significance.

- A Norfolk soil containing 0 and 2% biochar.
- Measured retained water by weight from each sample.
- WHC was consistently improved by all biochar applications over 118 days.

Findings of Novak et al., 2012

- Findings in Novak et al. 2012, suggest that certain feedstocks can be chosen and the pyrolysis conditions tailored to make designer biochars, in order to improve soil-moisture storage in soils with deficiencies or limitations.

- Samples of switchgrass biochar significantly improved soil moisture storage in a Norfolk Sandy Loam soil, in comparison to the control.



Mean gravimetric moisture contents of a Norfolk loamy sand treated with 20 g/kg biochars on successive days after being leached with 1.2 pore volumes of di. water (error bar = 1 SD; Novak et al. 2012).

Water Conservation **Research Findings**, OPR Biochar Research Advisory Group

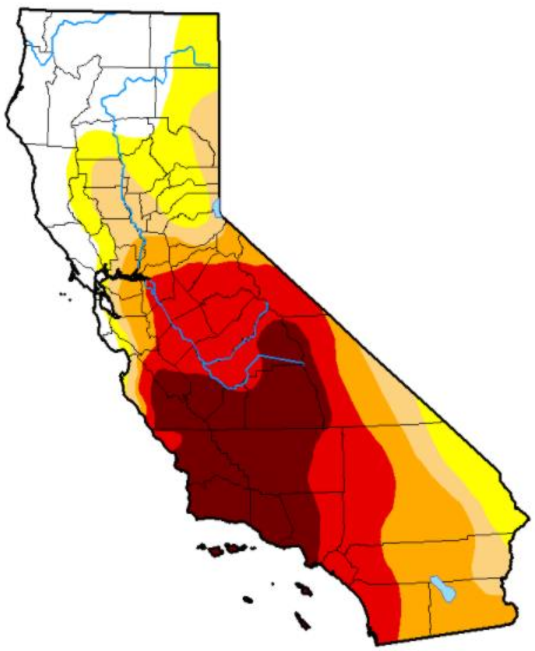
❖ *Under what conditions may biochar increase soil water retention (e.g., plant available moisture), in agricultural applications?*

- “Lashari et al., (2013) provide evidence which suggests that biochar improves the productivity of low organic matter desert soils. These authors reported detectable improvements in saturated hydraulic conductivity, soil water permeability, water holding capacity, and plant water availability following biochar addition to a sandy desert soil.” – Charles Sanchez, University of Arizona

- “Hydrophilic biochars with high surface areas would likely increase soil water retention. It will also promote the formation of soil aggregates which will also foster improved soil water holding conditions. It’s most likely to be effective in coarse textured soils that have low organic matter.” – Mark Johnson, US EPA

- “Biochar with highest specific surface area is likely to promote higher water retention in soil.” – Asmerete Berhe, UC Merced

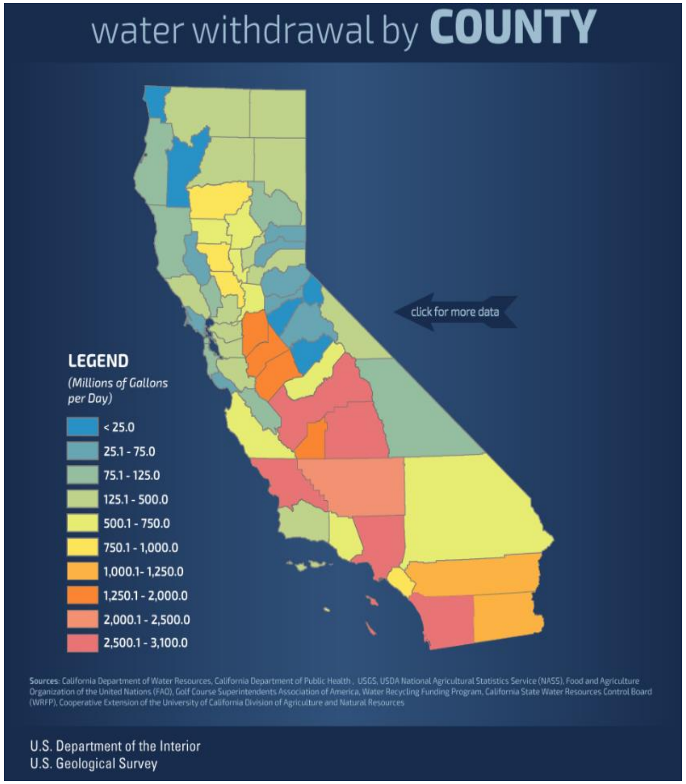
Drought and Water Use in California



U.S. Drought Monitor

California

December 27, 2016



Sources: California Department of Water Resources, California Department of Public Health , USGS, USDA National Agricultural Statistics Service (NASS), Food and Agriculture Organization of the United Nations (FAO), Golf Course Superintendents Association of America, Water Recycling Funding Program, California State Water Resources Control Board (WRFP), Cooperative Extension of the University of California Division of Agriculture and Natural Resources

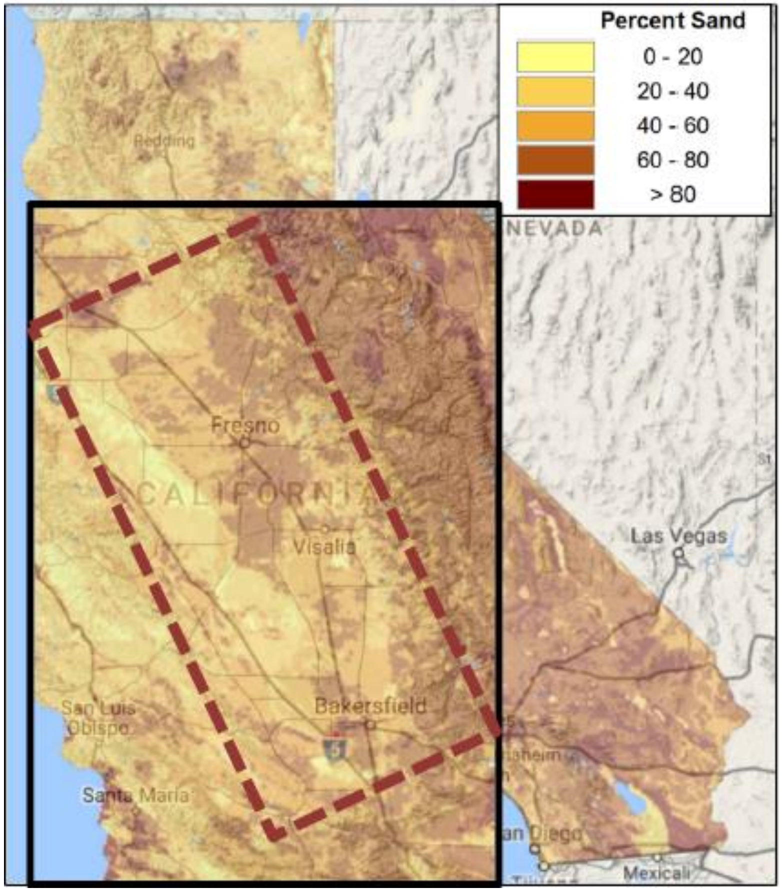
U.S. Department of the Interior
U.S. Geological Survey

- According to the US Geological Survey, in 2010 Californians used on average 38 billion gallons of water per day.

- Of that 38 billion, 22.8 billion gallons (or 60%) was allocated for irrigation purposes.

- **Concern**: Counties with the highest water withdrawal lie in regions impacted by drought.

Mitigate Drought in Central Valley Soils with Biochar



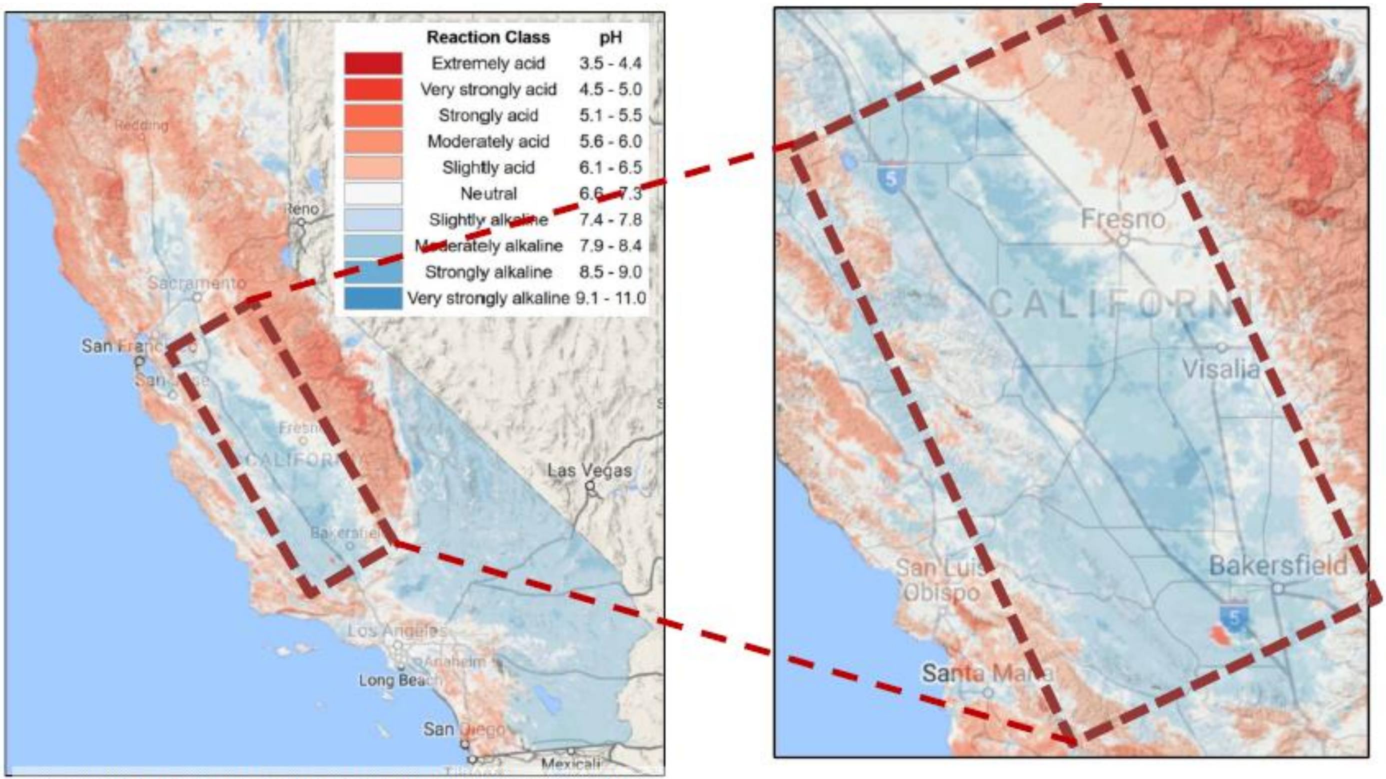
Map created with Soil Properties Ap (casoilresource.lawr.ucdavis.edu)

- Sandy soils retain little water because of their coarse texture, which commonly creates crop moisture stress over the growing season (Novak et al., 2012).

- According to Burrell et al. (2016), “a growing body of research into the effects of biochar on soil physical characteristics suggests that it is most effective in coarse-textured soils.”

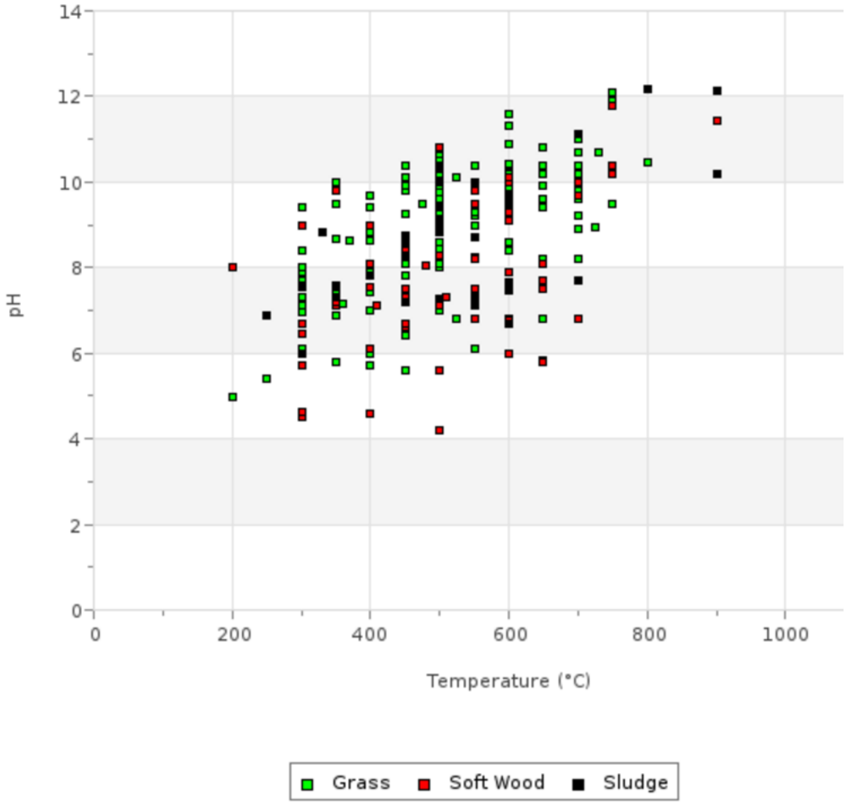
pH Concerns

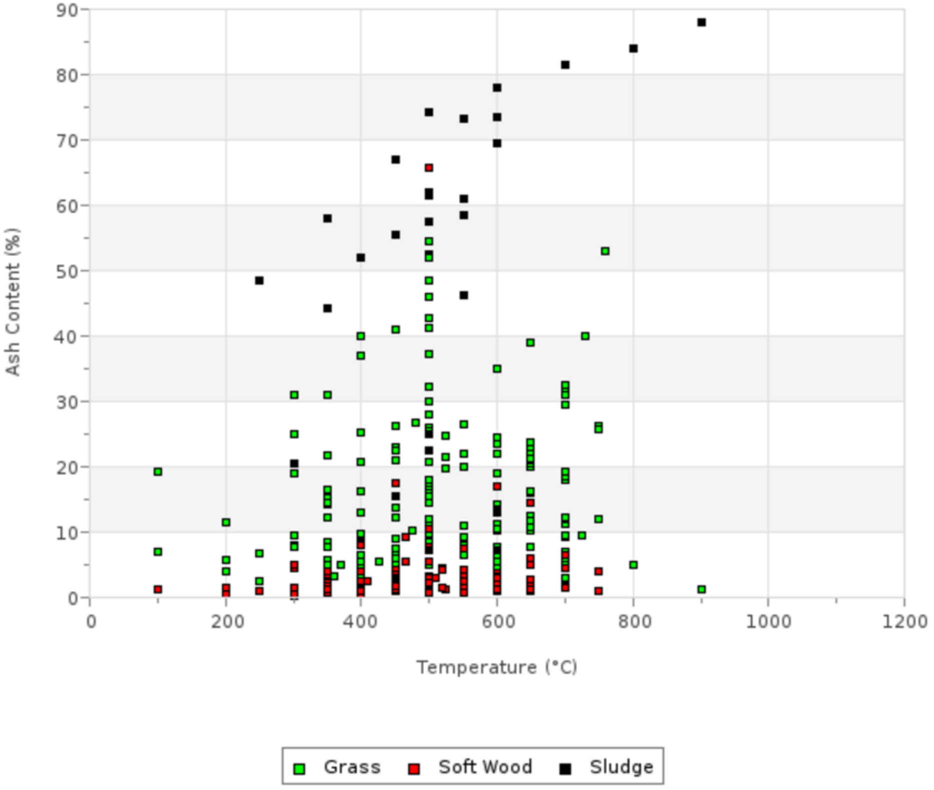
- High **Ash Content** biochars can negatively impact the pH of alkaline soils, in the central valley.
- Increases in soil pH can reduce nutrient availability to crops in alkaline soils but can increase nutrient availability in acidic soils.
- High Ash Content = High pH



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

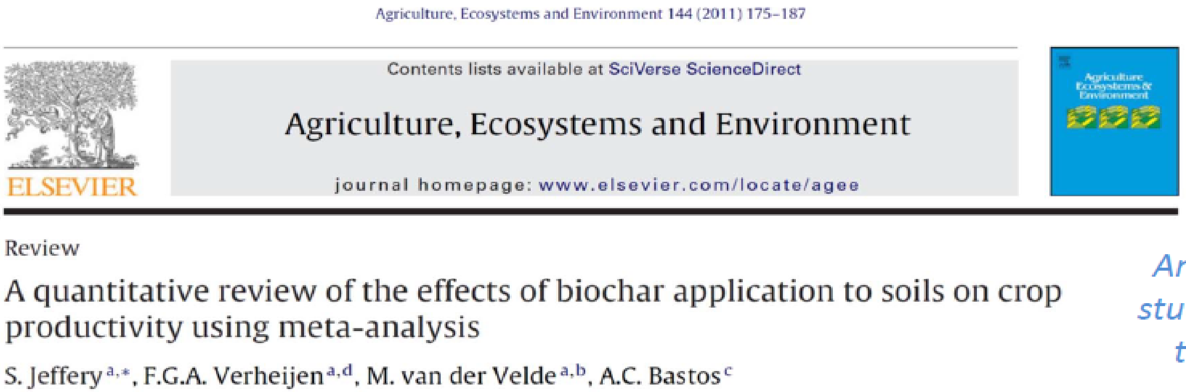
Use Proper Feedstock to Mitigate pH Concerns





- Soft woods tend to yield biochars with fairly low ash contents, and are thus the preferred feedstock choice for central valley soils.

Biochar Impact on Crop Yields



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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 the most benefits when it can impact:

- pH (“liming”), porosity, nutrient availability

Slide courtesy of Sanjai Parikh, UC Davis.

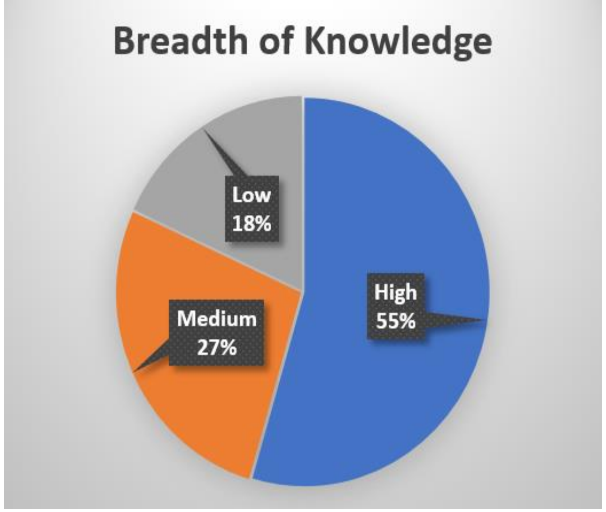
Crop Productivity **Research Findings**, OPR Biochar Research Advisory Group

❖ *Under what conditions are crop productivity benefits most commonly observed?*

- "Nutrient poor soils appear to have the most opportunity to achieve significant yield improvements. Less understood are yield improvements in nutrient rich soils."
  – Dan Munk, UC ANR

- "Jeffery et al. (2011), reported crop productivity benefits in acidic and neutral soils and in course or medium textured soils."
  – Michelle Leinfelder-Miles, UC ANR

- "In general, the literature shows that biochar benefits to crop productivity are greatest in very poor, degraded soils, and/or coarse-textured soils."
  – Jessica Meisel, Michigan State University



Over half of the researchers who responded to this question (6 of 11), indicated that there was a high breadth of knowledge in this area of interest.

Crop Productivity **Research Gaps**, OPR Biochar Research Advisory Group

- "Need for much more information on specific combinations of biochar type, soil, and crop." – Jessica Meisel, Michigan State University

- "More and longer-term and larger field trials will always be desirable. Also, a coordinated effort, either regional, national or global, is desirable to allow cross-climatic and edaphic comparisons (e.g., by including a shared biochar across sites, harmonizing application rates and method." – Johannes Lehmann, Cornell University

- "In Jeffery et al. (2011) meta-analysis of 16 studies, only one study was conducted in a temperate climate, and all other studies were conducted in tropical or subtropical climates. This indicates the results of biochar application to CA agricultural soils are still largely unknown. Additionally, of the 16 studies, none were conducted for more than 2 years." – Michelle Leinfelder-Miles, UC ANR

State's Current Engagement with Biochar

- Assembly Bill 2511
  - State Definition of Biochar: "Biochar means materials derived from thermochemical conversion of biomass in an oxygen-limited environment, containing at least 60 percent carbon." (2015-2016 Legislative Session)
  - Created a CDFA biochar certification program
  - Food and Agriculture Code section 14513.5, authorized under AB 2511

- Senate Bill 859
  - Section 9: Wood Product Utilization Working Group
  - Evaluated the economic value of biochar as a possible recommended product from tree mortality biomass

- OPR's Biochar Research Advisory Group
  - Evaluate the available scientific literature and prepare future policy recommendations

- CDFA and DWR currently fund several biochar research projects at UC Davis and UC Riverside.

- Encourage and support the development of additional biochar field trials and demonstration projects.

Crisis to Opportunity

Biochar production can be an alternative waste stream management strategy for forestry and agricultural waste biomass. This **Best Management Practice** has the potential to enhance the State's capacity to achieve the following environmental goals:

- Climate Change Mitigation
- Drought Mitigation
- Improve Soil Health
- Increase Crop Productivity
- Biomass Waste Reduction

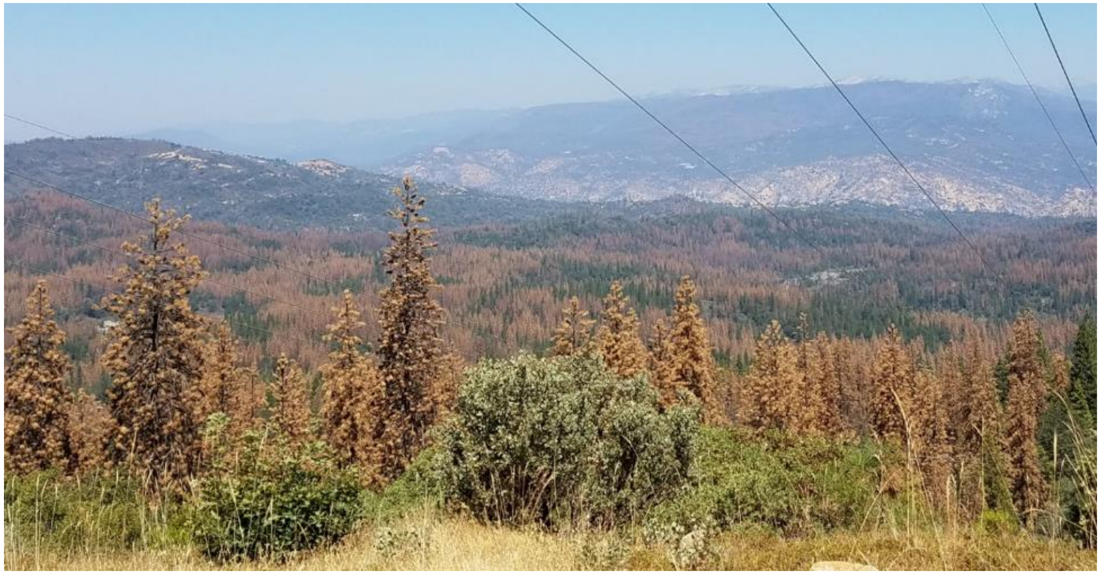


Image taken on 8/12/2016, in the Sierra National Forest (High Hazard Zone)

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