

# Biochar formulations as a soil amendment in the agricultural, forestry and environmental sectors

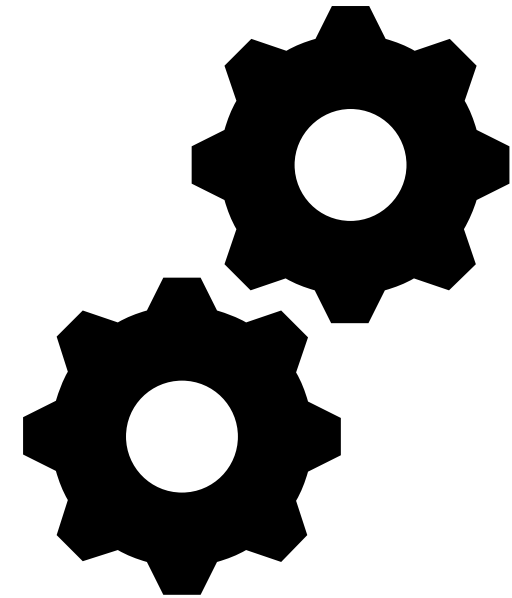
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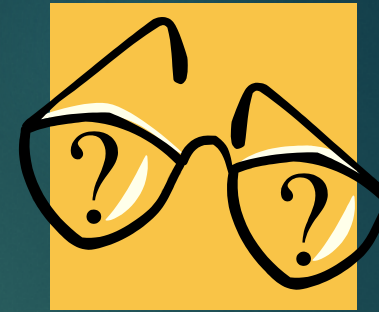


# Outline:

- ▶ What is biochar and a history of its usage?
  - ▶ Current production methods
  - ▶ Biochar characteristics
  - ▶ Designing biochars as soil amendments
  - ▶ Biochars impact on soil fertility and moisture retention
  - ▶ How do we formulate biochar for use in:
    - Agricultural, Forestry and Mine Spoil Remediation (Examples)
- Conclusions
- Questions/Answers



# Biochar terminology:



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- ▶ Biochar is a recent term used to describe charred organic matter applied to soil for soil quality improvements (*Lehmann and Joseph, 2009*).
- ▶ Popular terms to describe alternate C-enriched residues:
  - ▶ *Charcoal, black carbon, char, activated carbon*



*Charcoal—courtesy of K. Spokas*



*Biochar—courtesy of K. Spokas*



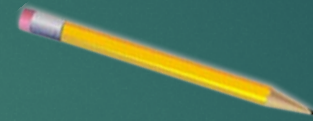
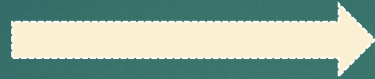
*Activated C—M. Ahmenda*

# Historical uses of charcoal, black carbon, char, etc.

- We have used these materials in the past...and currently



Cave Drawings  
(>10,000 to 30,000 BC)



Pencils



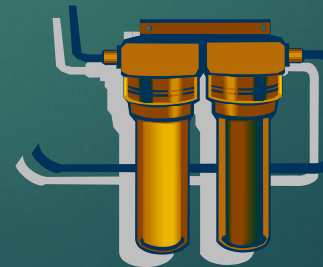
Used as fuel  
(3000-4000 BC)



Charcoal production  
(15<sup>th</sup> century)



Water filtration  
(2000 BC)



Activated Charcoal  
Filtration Today

*Courtesy of Kurt Spokas (ARS-St. Paul)*

# Charcoal, black carbon, and biochar usage continuum:

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## ➤ Recent biochar usages:

As a soil amendment in Agricultural and Forestry

In mine spoil remediation



Formosa Mine Spoils

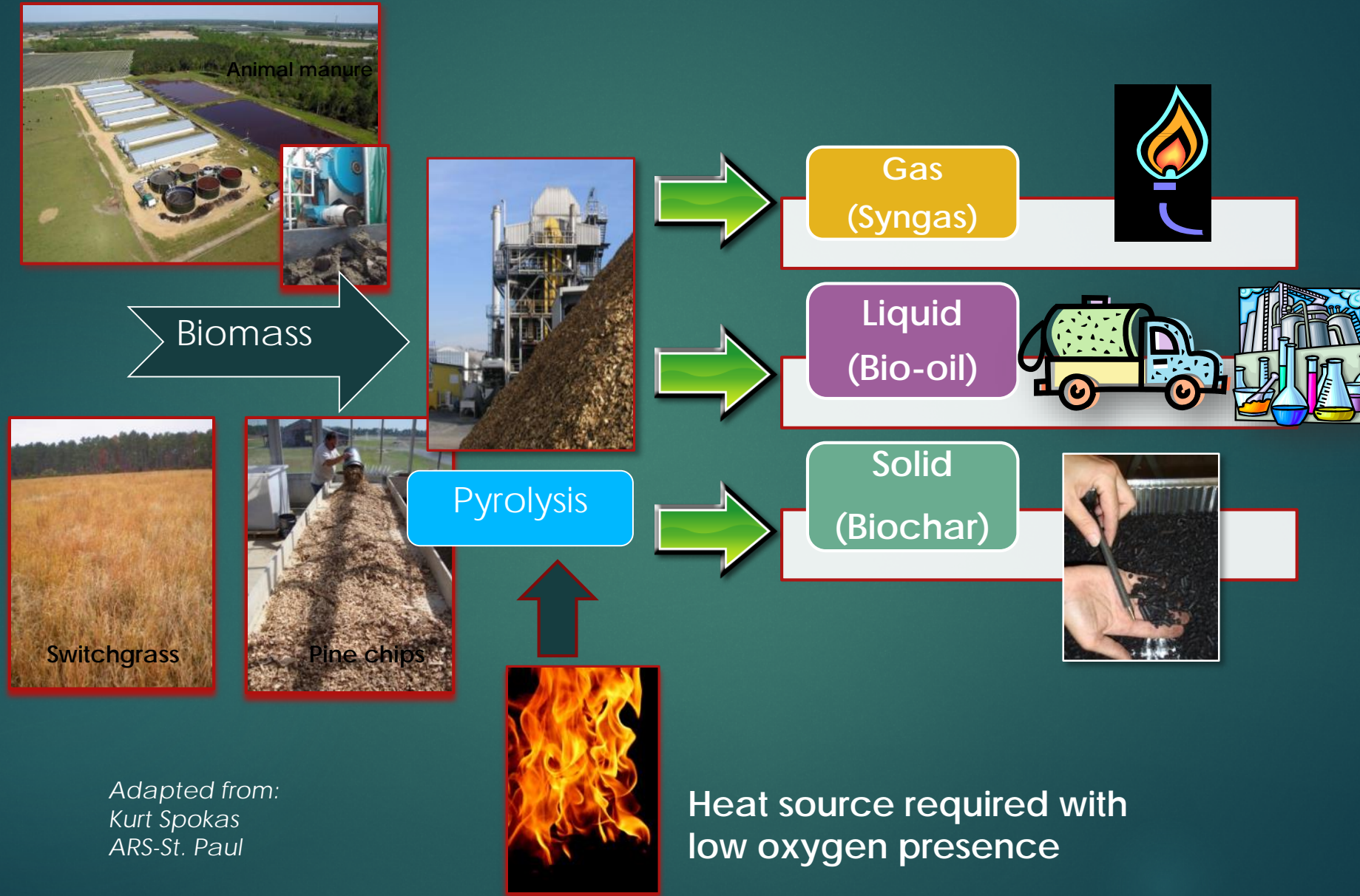


Forestry debris in PNW



Agriculture

# Current production methods:



Adapted from:  
Kurt Spokas  
ARS-St. Paul

Heat source required with  
low oxygen presence

# Pyrolyzers: Field and laboratory

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Torrified wood flakes  
(250-275°C)



Lab scale pyrolyzer  
(Switchgrass 350°C)

# Commercial scale pyrolyzers:

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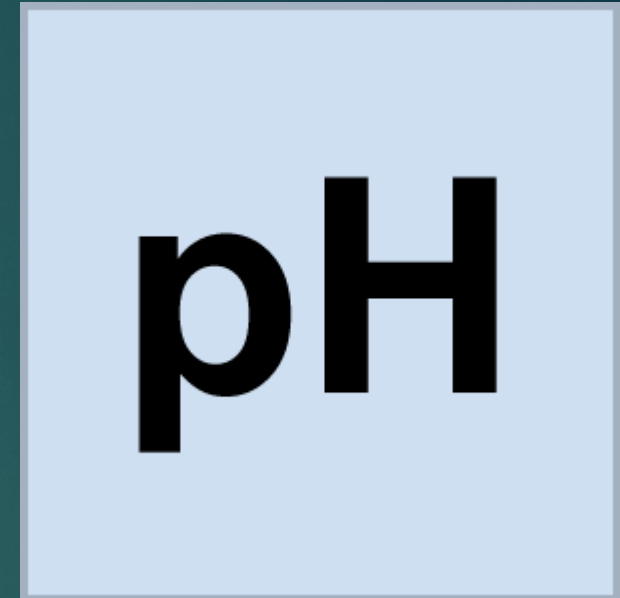
- ① Slow to fast pyrolysis (h to s)
- ② 400 to 700°C
- ③ Can produce up to tons/day
- ④ Sometimes heterogeneous batches



Lodgepole pine chip biochar (500°C)

# Biochar characterization (pH)

Feedstock	Pyrolysis (°C)	Mean pH (H <sub>2</sub> O)	Source
Wood	400	6.9	Singh et al. (2010)
	500	8.8	
Cow manure	400	9.0	Singh et al. (2010)
Hardwood	450	8.8	Jones et al. (2012)
Pecan shell	350	5.9	Novak et al. (2009a)
	700	7.2	
Poultry litter	350	8.7	Novak et al. (2009b)
	700	10.3	
Pine chips (n = 1)	465	6.1	Novak and Busscher (2012)
Corn stover (n = 1)	500	7.2	

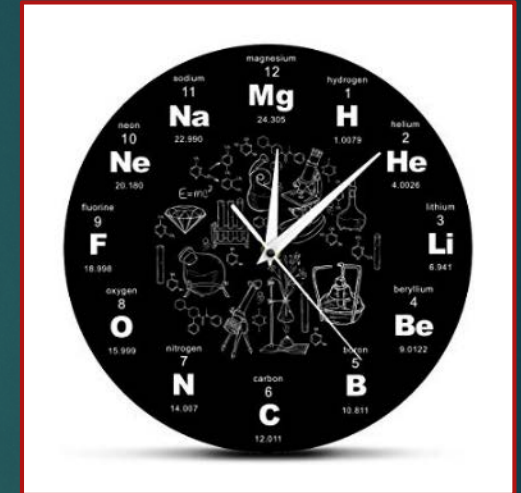


As pyrolysis temperature increases, biochar pH will also increase

# Biochar characterization (nutrients):

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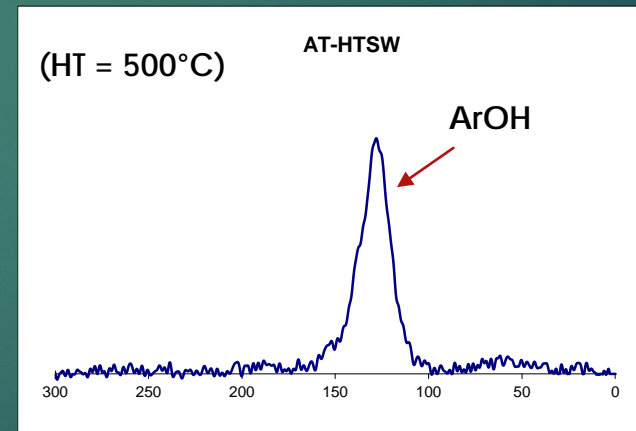
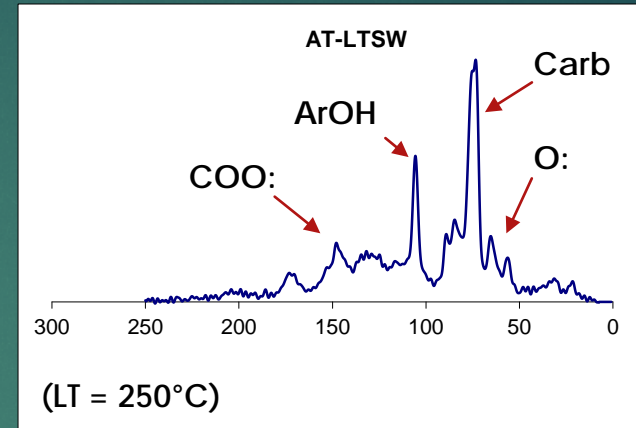
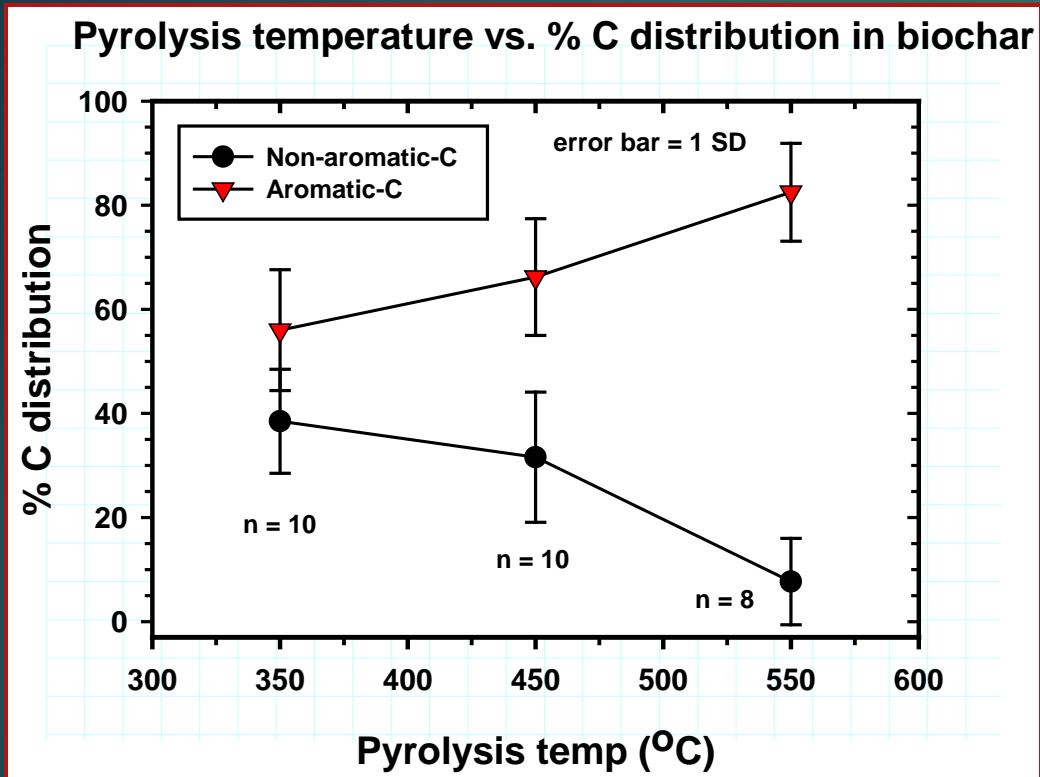
Feedstock	Pyrolysis (°C)	Fertilizer equivalent ratio (kg/t biochar)			Source
		N	P	K	
Swine manure	350	37	39	18	Cantrell & Martin, 2011
	700	26	59	26	
Cow manure	400	14	4	26	Singh et al. 2010
	550	11	5	23	
Poultry litter	350	50	30	60	Novak et al. 2009b
	700	30	40	90	
Pine chips	350	5	0.2	2	Novak et al. 2012
	500	4	0.3	3	
Switchgrass	250	4	1	5	Novak et al. 2012
	500	11	2	12	



Biochars made from manures have higher fertilizer equivalent N P K ratios, and as pyrolysis temperature increases (> 500°C) N declines, P & K increase.

# Biochar characterization (structural):

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The structural properties of biochar is important because it controls its CEC, participation in redox reactions, and its longevity in soil.

<sup>13</sup>C NMR spectroscopy reveals:

- ① low pyrolysis temp (350°C) leaves aliphatic and polysaccharides compounds
- ② high pyrolysis temp (>500°C) mostly aromatic compounds remain



# So how do we use all this biochar information?

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- ▶ **Goal: Restore/improve spoil for plant growth—Consider this:**
- ▶ Identify the spoil problem that needs to be modified, including:
  - ▶ Fertility (pH, SOC, nutrients, etc.)
  - ▶ Microbial (enzyme activity, microfloral, etc.)
  - ▶ Physical (water retention, aggregates, BD)
  - ▶ Pollutant (heavy metals, organics, etc.)
  - ▶ Ground water quality (PFOS, PFOA and their monomers)



Formosa mine spoil (2015)

# Designing relevant biochars accomplished by selecting/manipulating:

SE USA sandy soils

Single feedstock/blend	Pyrolysis (°C)	Particle size	Soil impact
Switchgrass	250 to 500	Dust (< 0.42-mm)	+ water storage
Hardwoods	350 to 700	Dust (<0.42-mm)	+ water storage
Pecan shells	700	Dust (< 0.42-mm)	+nutrients/lime
Loblolly pine chips	350 to 700	Dust, pellets (> 2-mm)	C sequestration
Pine chips/poultry litter	350 to 700	Dust, pellets (> 2-mm)	C sequestration & balance soil [P]

Mine spoils/soils

Miscanthus	500	Flakes (2-6 mm)	Metal binding & enzymes
Lodge pole pine	500	Flakes (2-6 mm)	Metal binding
Poultry litter & beef cattle manure	500	Flakes (2-6 mm)	Metal binding, liming & soil microbiology



Biochar as pellets mixed into a Norfolk loamy sand

*Novak et al., 2009; Novak and Busscher, 2012; Novak et al., 2014, Sigua et al., 2016, Novak et al. 2018; 2019.*

# Designer biochar soil incubations (Novak et al. 2014)

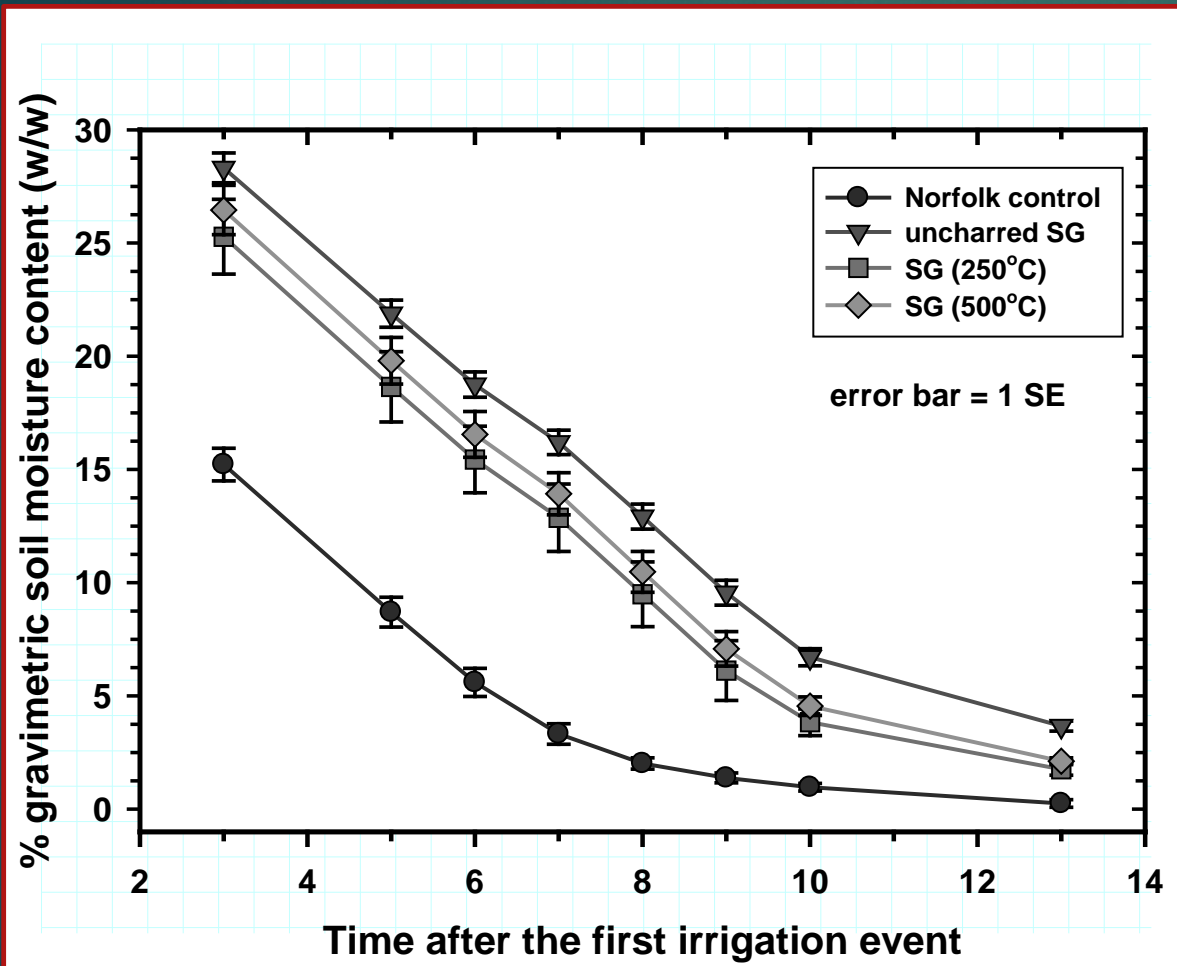
Biochar blends†	Blending ratios (w:w)	Mehlich 1 extractable P (mg/kg)	
		Pellet (> 2-mm)	Dust (< 0.42-mm)
Norfolk control	0 biochar	11 (2)	
PC + PL	100:0	11 (1)	11 (2)
PC + PL	0:100	52 (16)	237 (7)
PC + PL	50:50	73 (15)	113 (3)
PC + PL	80:20	22 (4)	29 (2)
PC + PL	90:10	19 (3)	23 (2)

†Biochars added at 10 g/kg soil and incubated for 75 d; PC = pine chip and PL = poultry litter.

Biochar was designed through feedstock blending and char morphology to increase Norfolk loamy sand plant available P content (Mehlich 1) to values recommended for a corn crop (30-50 mg/kg; 100 bu corn/ac).



Daily mean soil moisture contents (w/w) measured after the first irrigation event on a Norfolk loamy sand treated with uncharred switchgrass (SG) and two switchgrass biochars (error bar = 1 standard error, SE; Novak and Watts, 2013).



Uncharred Switchgrass (SG) impacted soil water retention > 2 SG biochars > Norfolk control (0 biochar).

# Using Biochar in Forest soils:



Chipping of waste forestry material



Mobile charcoal/biochar production and pelletizer system and method

# NO-TILL FOREST BIOCHAR TREATMENTS:

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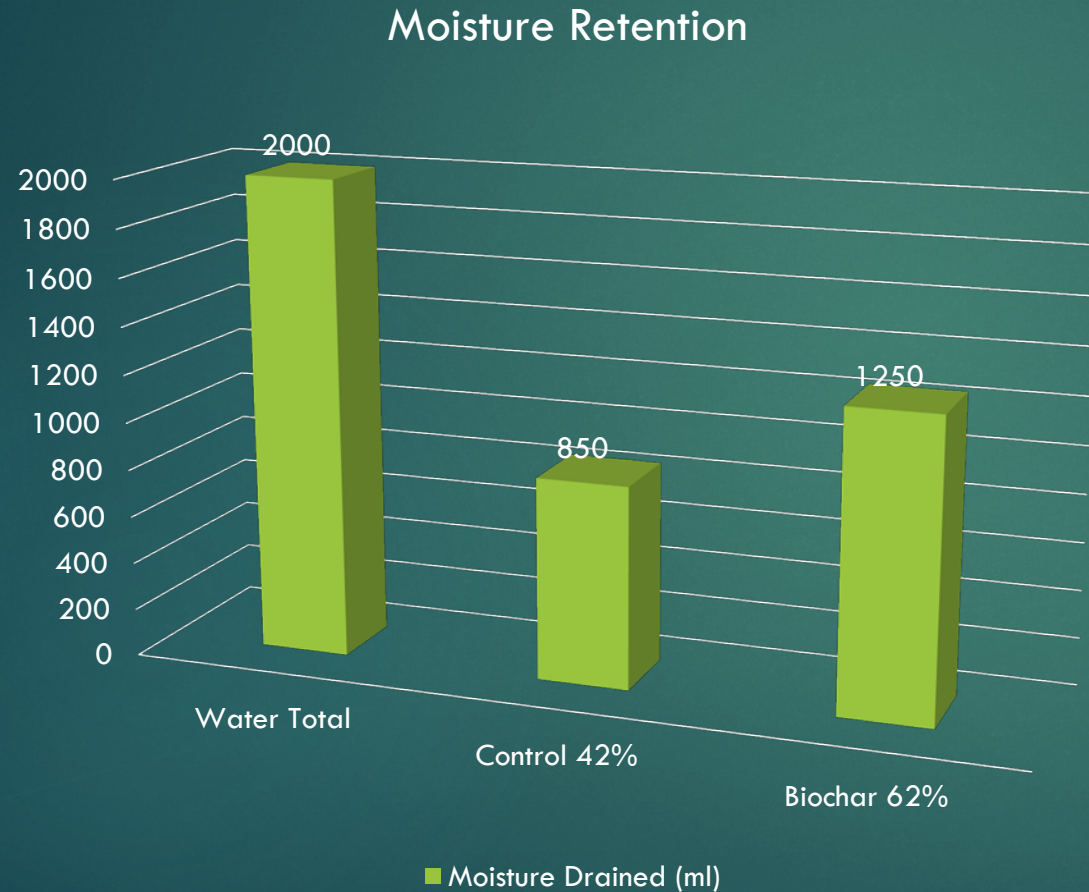


**20T/AC APPLICATION IN LIGHT RAIN**



**NEXT DAY BIOCHAR TRANSLOCATED BELOW DUFF**

# Biochar use on a pumice soil (Umpqua National Forest, OR)



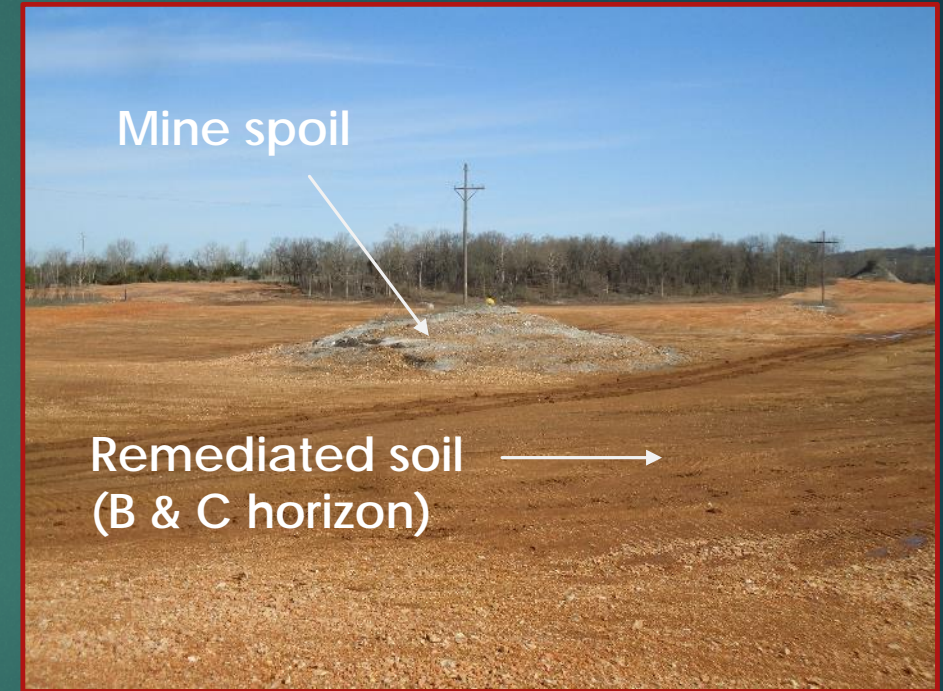
Biochar added (2.5 T/ac) to a soil test core retained more water.

## Formosa mine site, Riddle, OR



- Mine spoil is acidic ( $\text{pH} < 3$ )
- Cu and Zn levels promoted poor soil:plant relationships
- Poor water retention

## Tri-State mine site, MO



- Remediated soil is high in Zn and Cd
- Poor soil fertility (low SOC)
- Poor plant growth conditions

# Coordinate biochar types for use in a Switchgrass growth experiment with Tri-State Mine soil (Novak et al. 2019)



% Application rate (w/w)	
<u>Biochar</u>	<u>Manure compost</u>
0	0
0	2.5
0	5
2.5	0
2.5	2.5
2.5	5
5	0
5	2.5
5	5

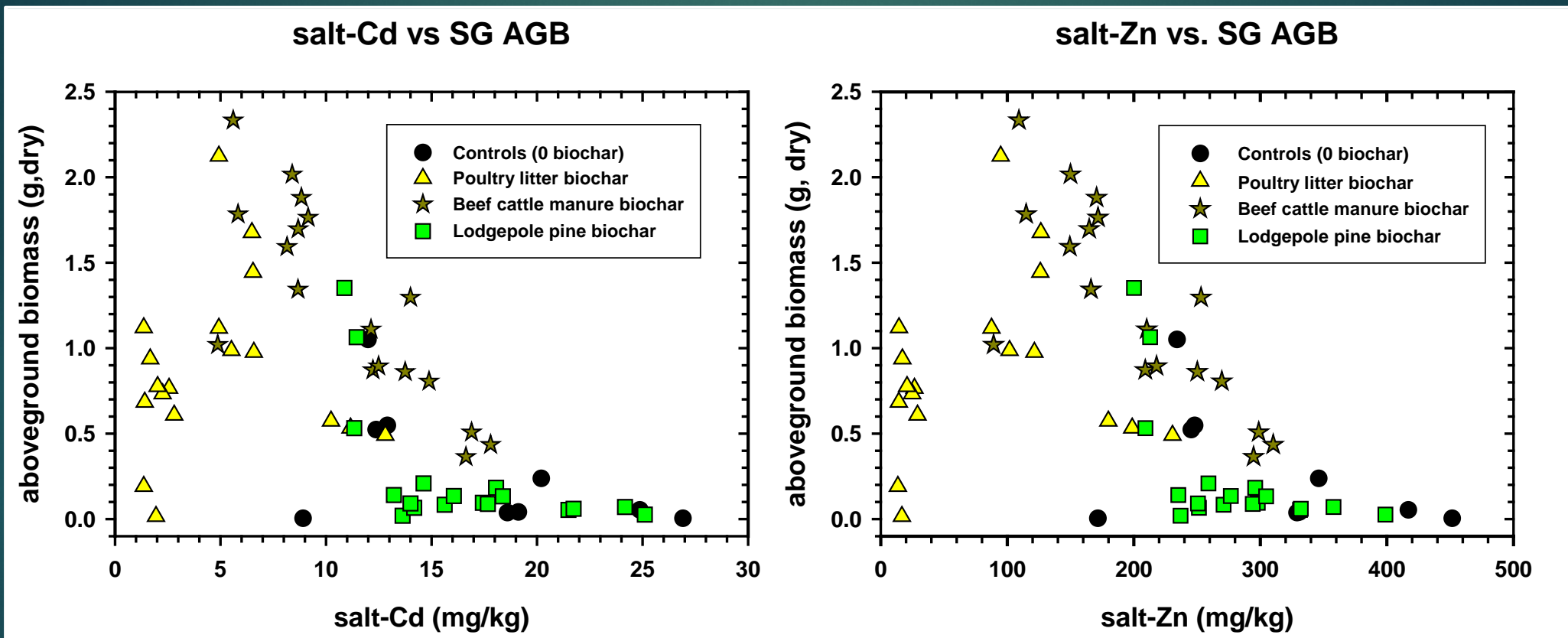
## What did we find?



Pot 112 is TSM treated with 2.5% lodgepole pine biochar & 2.5% manure compost.  
AGB = 0.084 g; pH = 4.8  
Salt-Cd = 135 mg/kg; Salt-Zn = 270 mg/kg  
Shoot-Cd = 135 mg/kg; shoot-Zn = 2,961 mg/kg

Pot 86 is TSM treated with 5% beef manure biochar & 2.5% manure compost.  
AGB = 2.017g; pH = 5.76  
Salt-Cd = 8.4 mg/kg; Salt-Zn = 150 mg/kg  
Shoot-Cd = 44.5 mg/kg; shoot-Zn = 761 mg/kg

# Switchgrass (SG) above ground biomass (AGB) in TSM soil treated with biochars and manure compost (Novak et al. 2019)



SG growth was enhanced by biochars that raised soil pH and compost that sequester metals

# Treatment of Formosa spoil (Novak et al. 2018)



Blue Wildrye planted in Formosa spoil

Mean shoot weight of Blue Wildrye (n= 4)		
Spoil + char (w/w)	No lime	Lime
0	0.0 a, A	0.245 b, A
1	0.001 a, A	0.384 b, A
2.5	0.004 a, A	0.317 b, A
5.0	0.007 a, A	0.322 b, A
<b>Factor</b>	<b>P</b>	
Biochar	0.456	
Lime	< 0.001	
Biochar * Lime	0.480	

Lime outperformed the Miscanthus biochar at influencing mean shoot weight. But, biochar reduced metal concentration in leachates.

# Remediation of the Formosa mine site:

## Phase 1 (2017-2018)



120 holes dug in mine spoil



Biochar + biosolids + lime added



120 Pine trees planted (2018)



100 pine trees survived (2019)

## Phase 2 (2018-2019)



Spoil preparation grass/forbes



Spoil treatment



Prep of Grasses/Forbes



Grasses/Forbes planted

# Conclusions:

- Feedstock and pyrolysis temperature influences biochar characteristics.
- Must understand what soil characteristic needs improvement and for what purpose.
- Match the right biochar to the correct soil problem.
- Biochars can improve the quality of agricultural and forestry soils.
- Biochars can be successfully designed to remediate mine spoils.
  - Tri-State Mine spoils (heavy metal sequestration)
  - Formosa mine spoils (pH, SOC, and heavy metal sequestration)

# Questions/Answers:

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