Formulating appropriate mixtures of biochar and other amendments to remediate and stabilize metal-contaminated mine soils and promote plant growth

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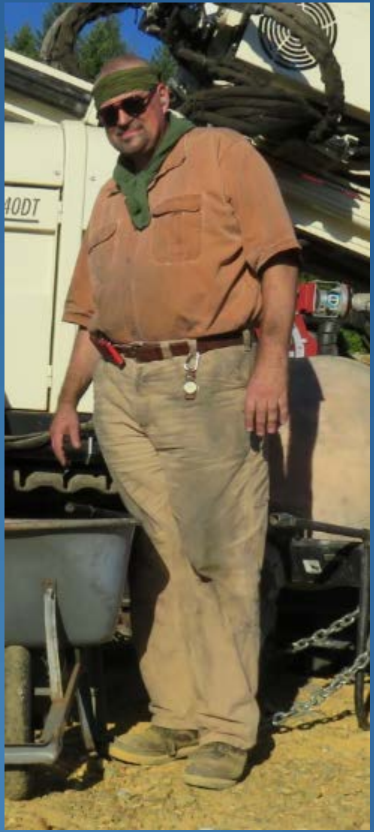
Biochar 2018
Wilmington, DE



What is the Problem?

Multiple problems

- **There are approximately 500,000 abandoned mines across the U.S. that pose a considerable and pervasive risk to human health**
  - World-wide the problem is even bigger
- **Contaminated soils and sediments require remediation**

Biochar when used as a soil amendment

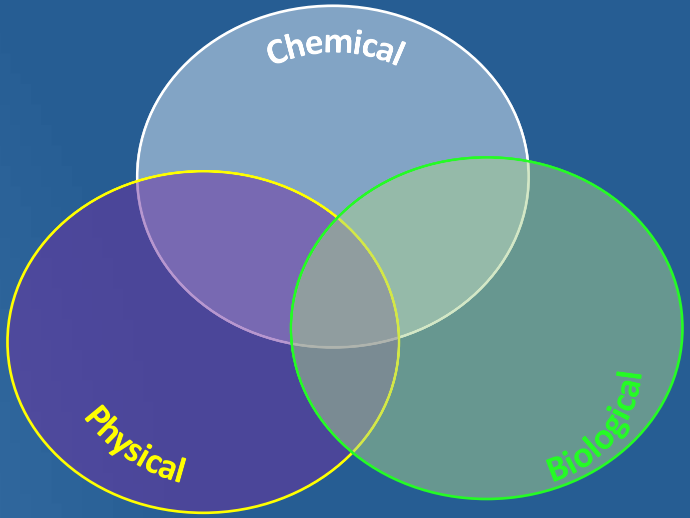
- **Has beneficial and tunable remedial properties**
- **Can reduce contaminant exposure by limiting the exposure pathways and immobilizing contaminants**
- **Can help to restore soil quality and health of degraded soils**
- **Can enable site *in situ* remediation, re-vegetation and revitalization, and reuse**

Mining Impacted Soils

Abandoned Formosa Mine, Riddle, Oregon USA

Mining Impacted Soil Limitations

- **Chemical**
  - Metal toxicity
  - Low: pH, Organic Matter, Nutrients
- **Physical**
  - Compacted
  - Coarse fragments
  - Poor structure
  - Poor water infiltration or holding properties
  - Depth of spoil material
  - Proximity to water table
- **Biological**
  - Low activity (e.g., plants, microbes, higher organisms)
  - Low diversity
  - Wrong kind of organisms



Establishing Remediation Targets

- Once you know what the problems are at your site, you need to determine the extent of adjustment required to provide sufficient site remediation to establish a sustainable native plant community

- Need a control site for comparison

- Develop and prioritize remediation/amendments selection and course of action

Remediating Contaminated Sites

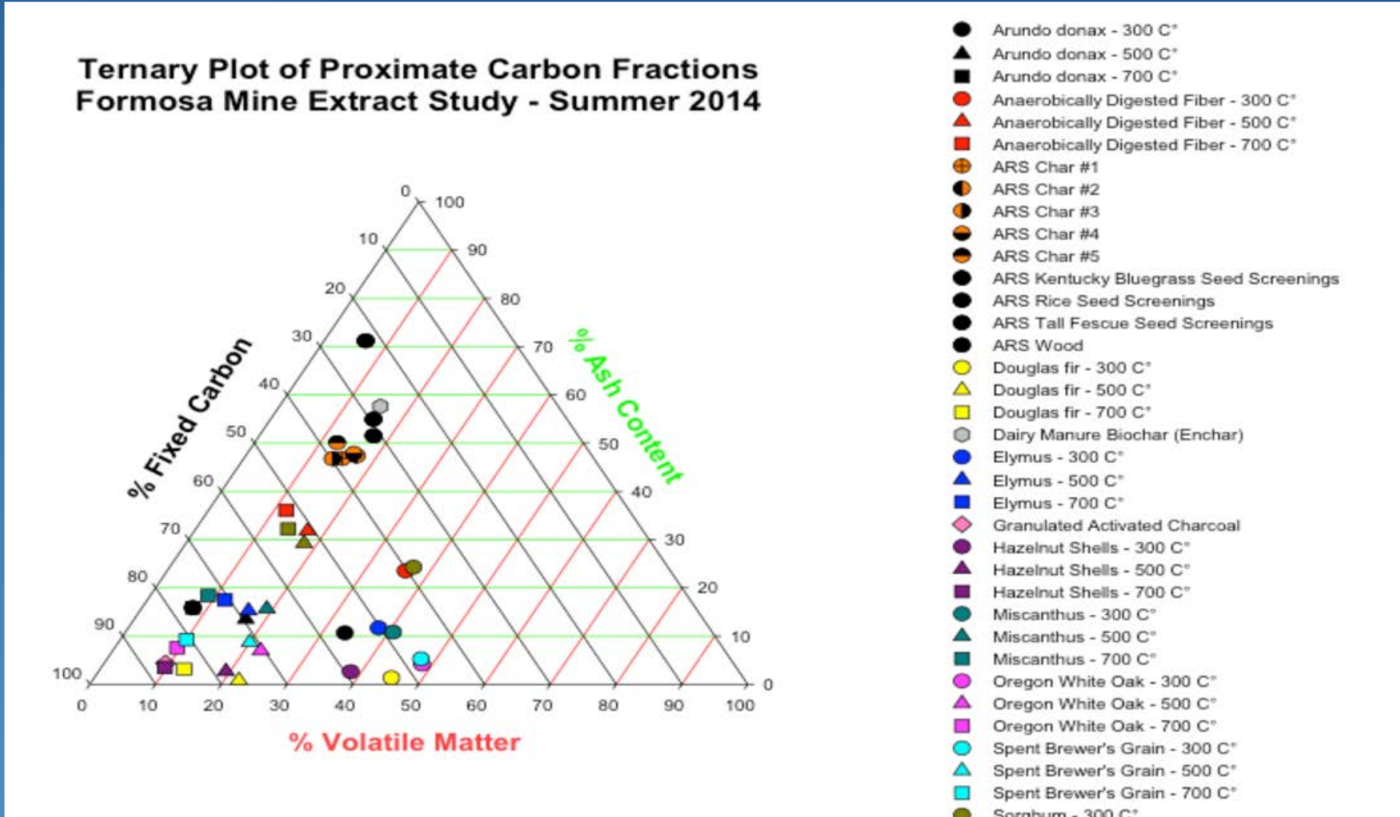
- Biochar has been shown to be effective at sorbing inorganic (i.e., heavy metals) and organic contaminants
- Biochar can be used to either raise or lower soil pH
- Increase and manage soil nutrient supply
- Biochar can improve soil water holding capacity
- Soil health (carbon sequestration, microbes, etc.)

Designer Biochar Concept

- It’s possible to design and make biochar with its own set of characteristics that can selectively improve soil properties.

- Biochars can be engineered from strategic permutations of feedstocks, blends of feedstocks, and a few key pyrolysis parameters to create “designer biochars” to address specific soil limitations.

Novak and Busscher, 2013; Novak et al. 2009; 2014



Mark Johnson, 2016

Other Soil Amendments can Include:

- Biosolids
- Manures/litters
- Sugar beet lime
- Wood ash
- Coal combustion products
- Log yard wastes
- Wastes from bioenergy production
- lime products
- Some metal oxides
- Composted biosolids
- Composted agricultural byproducts
- Composted yard wastes
- Mineral material
  - Foundry sands
  - Steel slag
  - Dredged sediments
  - Water treatment residuals
- Traditional agricultural fertilizers

Designer Biochar Approach

- ARS-scientists (Novak et al.) are engineering biochars to improve specific soil chemical, physical issues, and sorb P from manures.
- Accomplished by selecting/manipulating feedstocks and pyrolysis conditions:

Single Feedstock or Feedstock Blend*	Pyrolysis (°C)	Biochar Particle Size	Soil impact
Switchgrass	250 to 500	Dust	↑ water storage
Hardwood Chips	350 to 700	Dust	↑ water storage
Pecan Shells	700	Dust	↑ nutrients/lime
Pine Chips	350 to 700	Dust, Pellets	C sequestration
Pine chips + Swine Solids	350 to 700	Dust, Pellets	C sequestration & balance soil [P]
Switchgrass + Poultry Litter	350 to 700	Dust, Pellets	Water storage & balance soil [P]
Pine Chips + Hardwood Chips + Poultry Litter	350 to 500	Dust, Pellets	Water infiltration & root growth
Plant Biomass + Manure + Fe	>600	Variable	Microbial processes & P sorption[†]

**Novak and Busscher 2013; Novak et al., 2009; 2014*

Goals for Using Biochar and Other Soil Amendments on Metal Contaminated Sites:

- To immobilize metal contaminants thereby reducing their bioavailability and transport in the environment.
- To establish a sustainable native plant cover

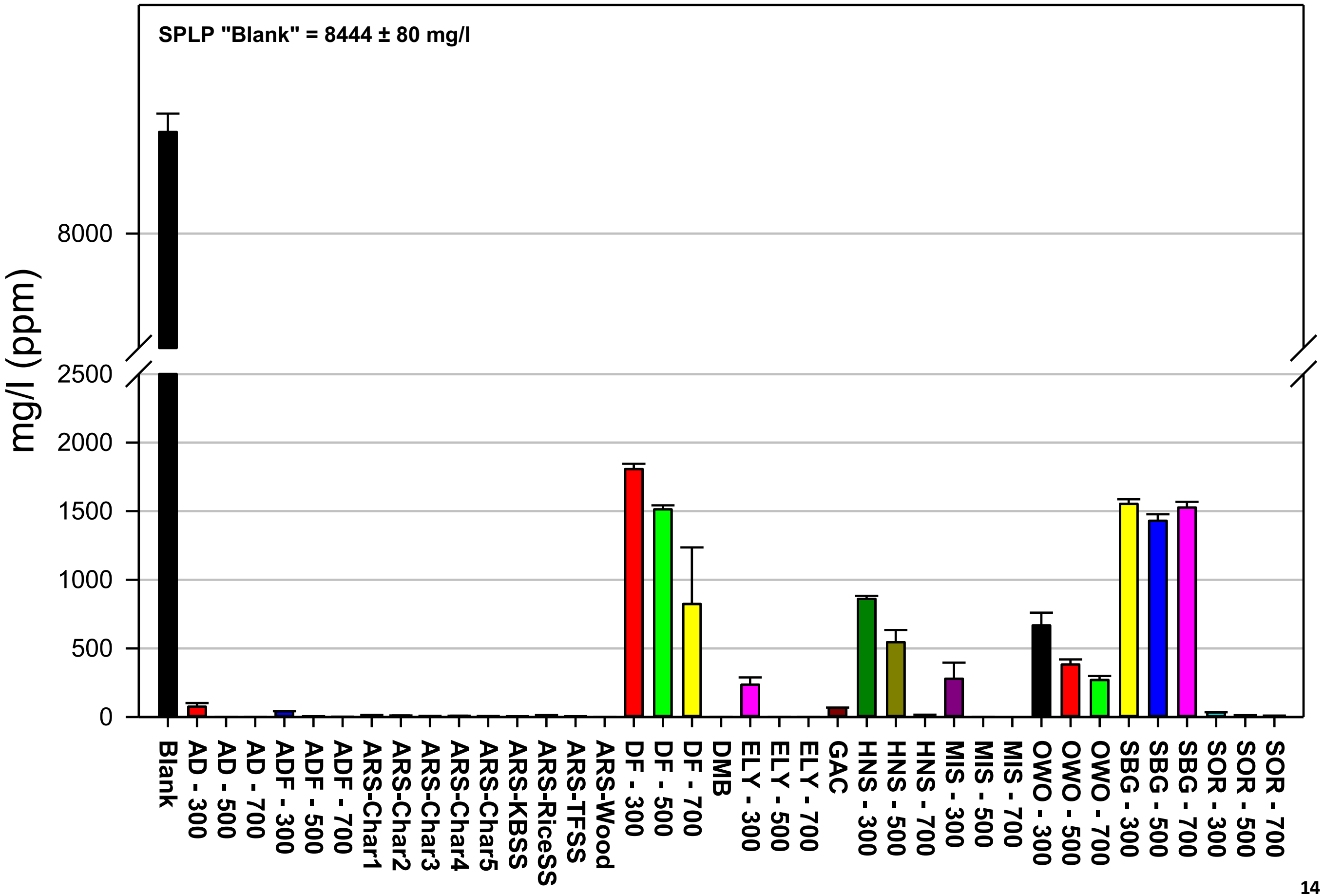
Screening Biochars

Three step laboratory process:

1. Challenge candidate biochars (we used 38 biochars from our "Biochar Library") with SPLP† extract of metal contaminated soil (Formosa Spoil Soil)
2. Determine metal binding characteristics of tested biochars
3. Select "best" biochars , as indicated from #1 and #2 above, and conduct a direct Formosa Soil:Biochar incubation to determine best performing biochar

†Synthetic Precipitation Leaching Protocol (EPA SW-846 Test Method 1312)
http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/1312.pdf

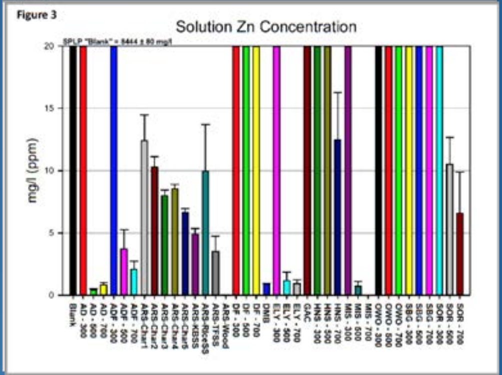
Solution Zn Concentration



Designing biochar to remediate mine soils

Many chars outperform activated charcoal

What do the ”best” chars have in common?



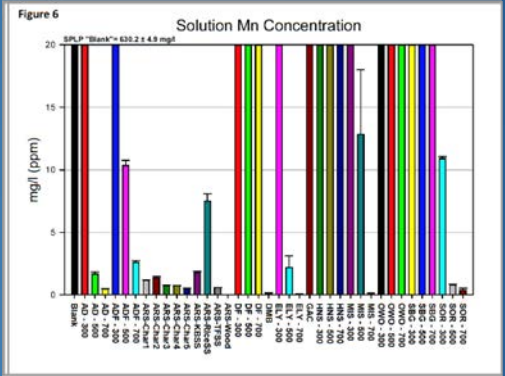


Table 2

% Removal of Initial Metal Concentrations in SPLP† Extract of Formosa Mine Soil After 24 Hour Contact with Biochar

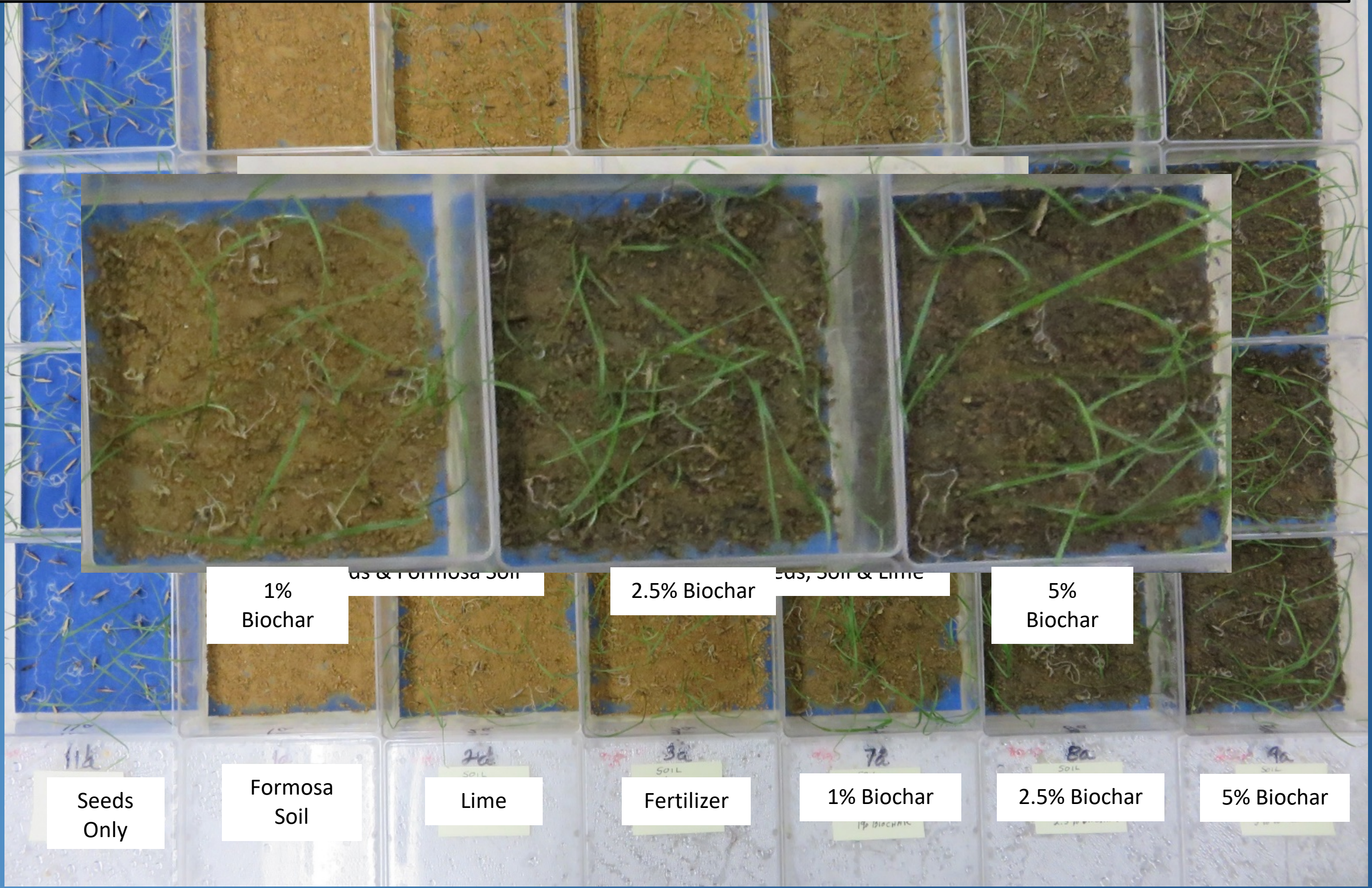
Formosa SPLP Solution Mean Metal Concentrations (ppm)				
Zn	Mn	Cu	Cd	Ni
8444.62	630.23	260.46	59.00	16.42

Biochar Code	% Zn Removal	% Mn Removal	% Cu Removal	% Cd Removal	% Ni Removal	Sum of Removal Percentages
ARS-Wood	100.00	100.00	100.00	100.00	100.00	500.00
MIS - 700	100.00	99.98	99.91	100.00	99.99	499.88
ELY - 700	99.99	99.99	99.77	100.00	99.76	499.50
DMB	99.99	99.98	99.48	100.00	99.97	499.42
ADF - 700	99.98	99.59	99.94	99.96	99.52	498.98
SOR - 700	99.92	99.94	99.60	99.89	98.93	498.28
ELY - 500	99.99	99.65	99.32	100.00	99.12	498.08
AD - 700	99.99	99.93	98.98	99.98	99.01	497.89
ADF - 500	99.96	98.36	99.77	99.93	99.38	497.39
ARS-TFSS	99.96	99.91	99.35	100.00	97.83	497.06
ARS-KBSS	99.94	99.72	99.30	99.89	98.12	496.98
MIS - 500	99.99	97.96	99.64	100.00	99.33	496.92
ARS-RiceSS	99.88	98.81	99.86	99.58	98.67	496.81
SOR - 500	99.88	99.88	98.88	99.82	97.85	496.30
AD - 500	100.00	99.73	98.46	99.89	98.10	496.18
SOR - 300	99.60	98.27	98.83	99.75	98.48	494.93
ARS-Char4	99.90	99.88	98.00	99.87	96.43	494.09
ARS-Char5	99.92	99.92	98.09	99.91	96.23	494.07
ARS-Char3	99.91	99.88	97.86	99.87	96.26	493.78
ARS-Char1	99.85	99.82	97.88	99.89	95.50	492.95
GAC	99.22	95.16	100.00	99.33	98.98	492.69
ARS-Char2	99.88	99.79	97.51	99.78	94.80	491.75
HNS - 700	99.85	91.53	99.78	99.77	98.30	489.23
AD - 300	99.11	94.32	99.05	99.74	96.56	488.77
ADF - 300	99.52	89.79	99.38	99.64	98.03	486.36
ELY - 300	97.22	91.25	99.49	98.96	95.01	481.92
OWO - 500	95.47	90.48	99.69	99.85	92.06	477.54
OWO - 700	96.81	86.88	99.88	99.70	91.63	474.91
MIS - 300	96.70	87.43	99.35	98.25	92.57	474.29
HNS - 500	93.54	84.61	99.48	96.26	90.62	464.51
OWO - 300	92.09	88.01	98.95	93.94	89.73	462.72
DF - 700	90.25	85.61	99.86	91.84	92.63	460.19
HNS - 300	89.81	83.18	99.30	94.88	89.68	456.86
DF - 500	82.08	79.48	99.78	84.58	84.06	429.98
SBG - 700	81.92	79.90	98.75	85.00	82.41	427.99
SBG - 500	83.07	80.69	97.42	84.76	80.12	426.06
SBG - 300	81.61	79.21	92.58	82.03	79.57	415.00
DF - 300	78.61	78.31	86.11	79.04	79.13	401.20

†SPLP = Synthetic Precipitation Leaching Protocol (EPA Method 1312)

Mark Johnson, EPA

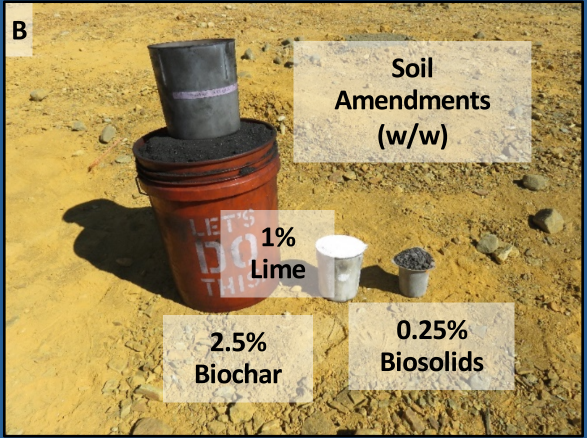
Establish % application rates in pre-trial seed germination study: Formosa Mine Spoil Soil, Amendments and Miscanthus Biochar



Greenhouse Trials for Formosa Mine: Dialing in Biochar and Amendments

Preparing the Formosa Site for Planting Trees (09/17)

A Excavating Spoil Soils



B Soil Amendments (w/w)

C Amendments and Soil in Mixer

D Placing Amended Soil Back in Excavated Hole

Formosa Mine Field Trials: Site Before Tree Planting

- 119 locations (0.4 meter diameter x 0.6 meters deep) amended with biochar (2.5%), lime (1%) & biosolids (0.25%)
- Locations have 3 meter x 3 meter spacing
- Trees from local seed sources were planted in November 2017
- Rhizosphere soil inoculated with native soil
- In early spring area between rows will be prepped and planted with native herbaceous plants

Formosa Mine Field Trials:
Planting Douglas fir Trees (11/17)

- 119 locations (0.4 meter diameter x 0.6 meters deep) amended with biochar (2.5%), lime (1%) & biosolids (0.25%)
- Locations have 3 meter x 3 meter spacing
- Trees from local seed sources were planted in November 2017
- Rhizosphere soil inoculated with native soil
- In early spring area between rows will be prepped and planted with native herbaceous plants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Summary

- Identify site soil limitations via site characterization
- Prioritize Limitations
  - Greatest limiting factor to least limiting
- Can biochar alone eliminate or reduce limitation(s)?
  - If yes, is a “designed or engineered” needed?
  - If no, are other soil amendments also needed?
- Test the efficacy of biochar to reduce or eliminate limitations
  - Use site soil extracts to challenge library of biochars
  - Identify the best biochar for reducing soil limitations
- Test the effects of biochar on plant material
  - Germination tests
  - Greenhouse pot studies
- Demonstrate *in situ* amendment efficacy with field plot-scale studies
- Proceed to full site remediation with biochar and other soil amendments
- Monitor site conditions
  - Make adjustments if necessary
  - Declare success when a sustainable cover of native plant material is established