Biochar Research at EPA, ORD, Pacific Ecological Systems Division

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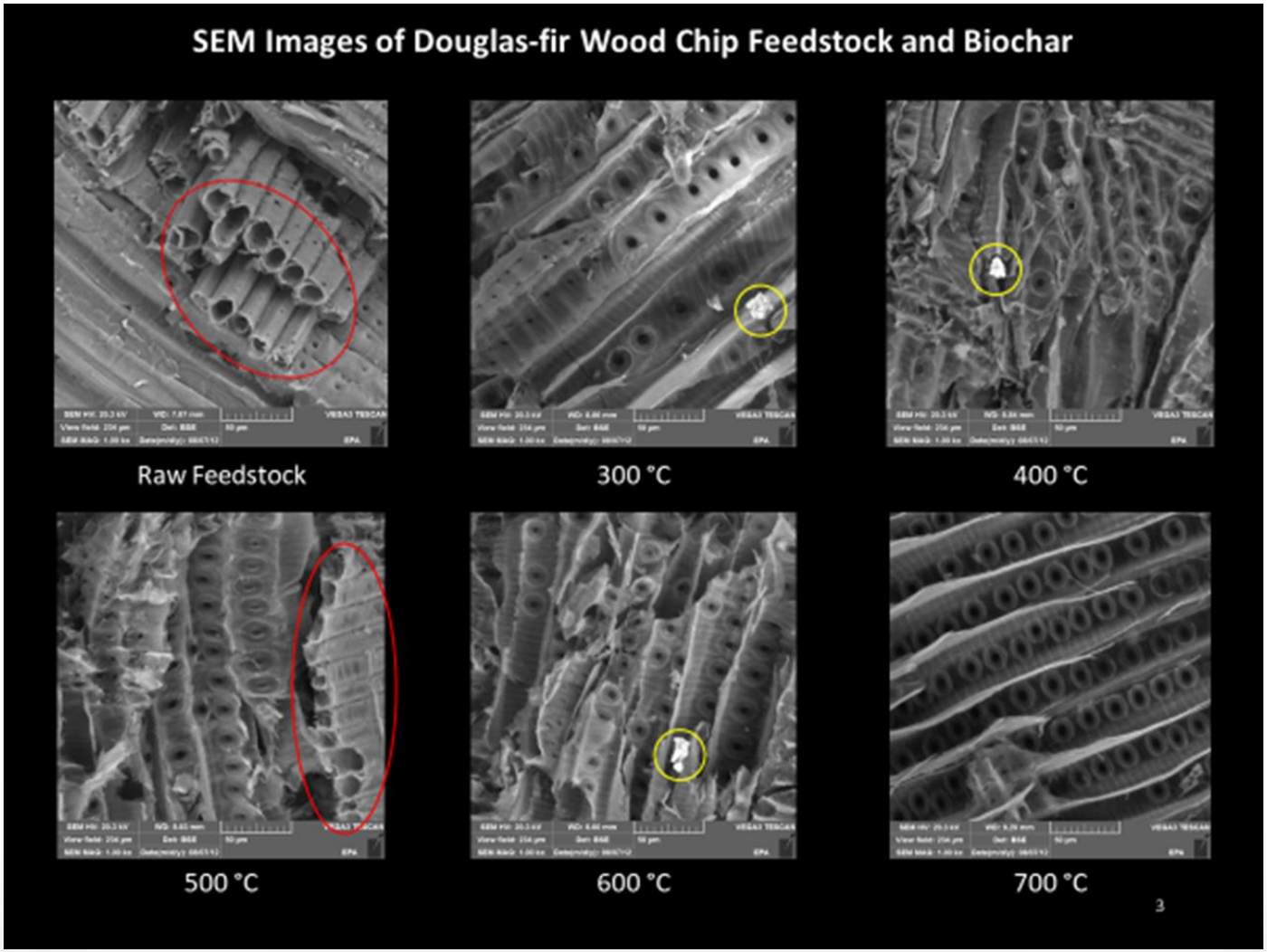
What Is Biochar?

- **The product of combustion of organic material with little or no oxygen (*pyrolysis* at lower temperatures (300-900° C), *gasification* at higher temperatures > 900° C)**

- **Gives remaining high stable carbon and high ash (inorganic mineral) content material with unique properties based on remaining elemental composition and structure**
  - Promotes carbon sequestration and soil quality
  - Source and sink for nutrients and improves soil nutrient retention
  - Promotes water uptake and water availability
  - Provides repository for soil organisms

- **Has wide application for soil and sediment problems**
  - Improve soil quality to enhance agronomic and phytoremediation performance
  - Immobilize hazardous/toxic/waste materials
    - Metals, Organic Chemicals, Pesticides, PFAS, Nutrients, ????

Biochar Structure



EPA - PESD Biochar Research Objectives

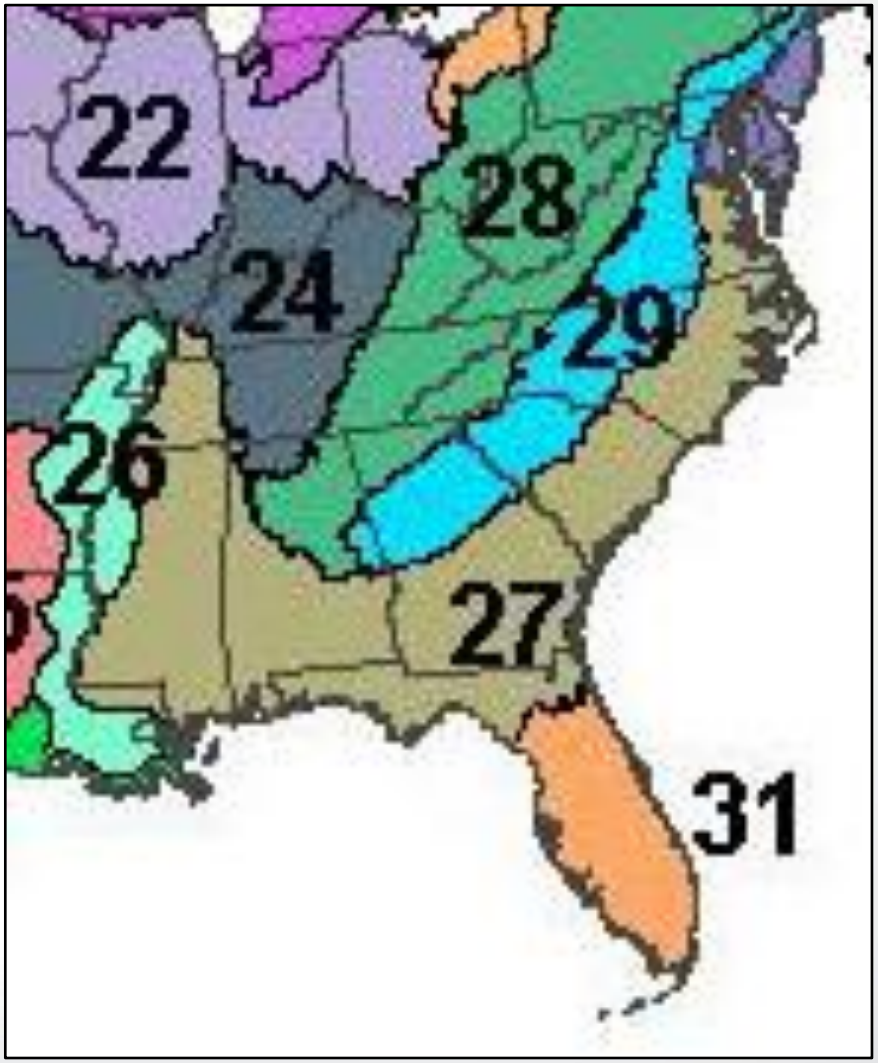
- **Agriculture**
  - Evaluate biochar's ability to improve degraded Coastal Plain soils while protecting the environment (Region 4) *
    - Beneficial use of agricultural and forestry waste by-products
  - Develop methods to use poultry litter biochar to lower Legacy soil P concentrations, capture mobile forms of P to reduce movement into Chesapeake Bay (new, Region 3)

- **Superfund Site Reclamation**
  - Develop amendments to enhance plant establishment to stabilize Cu and Zn mine tailings and reduce water contamination (Region 10) *
  - Determine if biochar can assist revegetation of Pb, Zn and Cd contaminated soils in the Tri-State Mining District area (Region 7)
  - Use biochar to remediate Pb-contaminated soils and sediments and to reduce methylation of Hg in (Region 10)

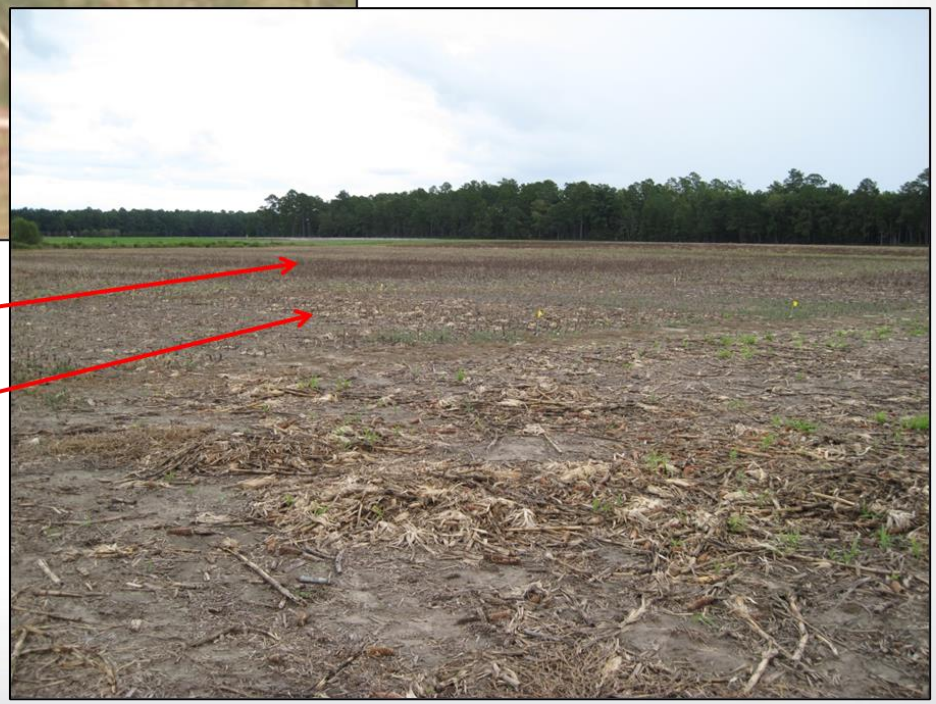
* Discussed in this presentation, not all of the results have been published yet

Biochar and Southeastern Coastal Plain Soils: Region 4

- Coastal Plain is area “27” on map
- Present to some extent in all 8 of the states within Region 4
- Soils are sandy with low organic matter content and low water retention
- Under intense agriculture production for 100+ years



Soil Associations Studied



Coxville Soil

Norfolk Soil

Primary Biochar Feedstocks: "Waste Materials"

Switchgrass

Pine Chips

Swine Solids

Poultry Litter

Determine Optimum Biochar Based on Variety of Feedstocks and Pyrolysis Temperatures

Feedstock	350 °C	500 °C	700 °C
Control	NA	NA	NA
Pine Chips (PC)	Yes	Yes	Yes
Switchgrass (SG)	Yes	Yes	Yes
Poultry Litter (PL)	Yes	Yes	Yes
Swine Solids (SS)	Yes	Yes	Yes
50 % PC & 50% PL (50:50)	Yes	Yes	Yes
80 % PC & 20% PL (80:20)	Yes	Yes	Yes

6 Feedstocks x 3 Pyrolysis Temperatures = 18 Biochars + Control = 19 Treatments

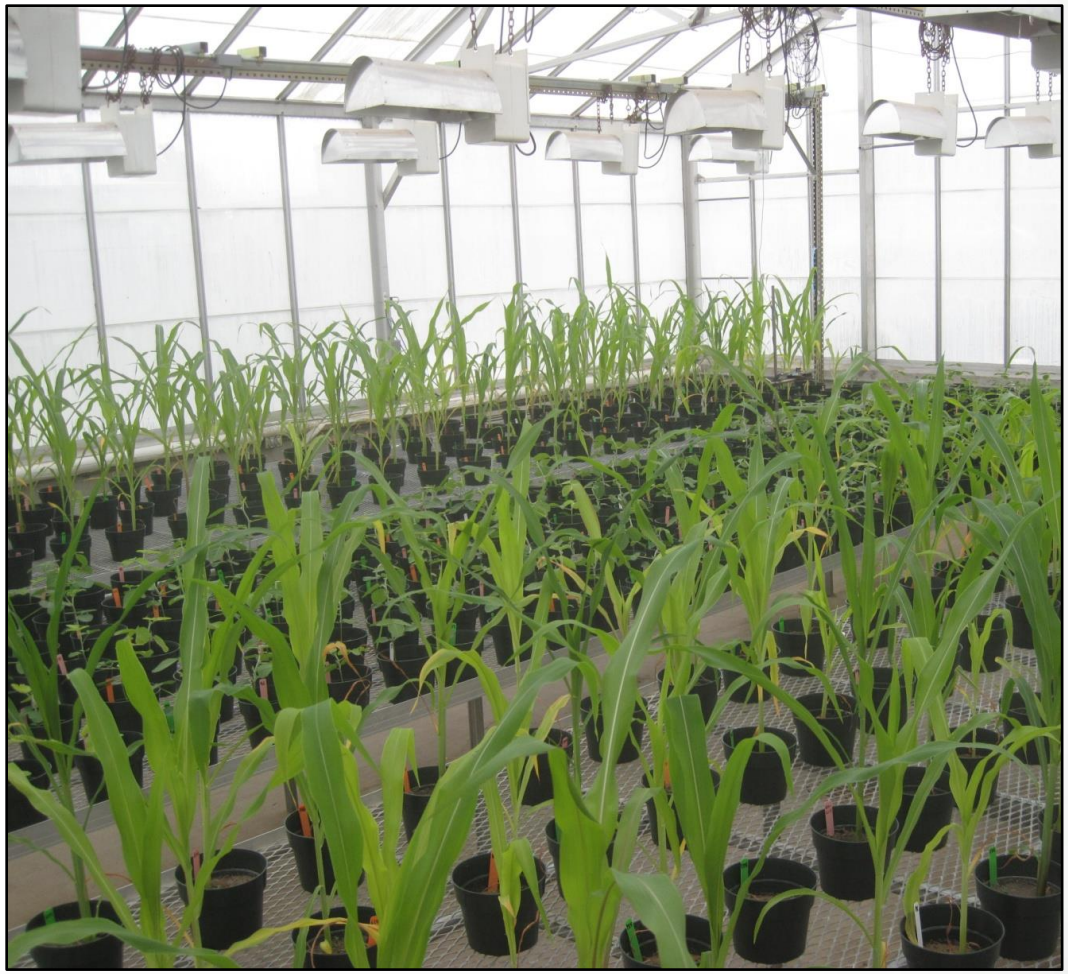
Soil, Biochar, Plant Studies: Corvallis

- Goal
  - Soil quality improvement for better crop growth, large-scale screening study to determine best biochar composition
- Two Coastal Plain Ag Soils
  - Norfolk
  - Coxville
- 18 Biochars
  - Local feedstocks
  - 3 pyrolysis temperatures
- Greenhouse studies
- ~60-day duration
- 4 Test Crops
  - Sweet Corn
  - Soybeans
  - Lettuce
  - Carrots
- Soil, plant and leachate chemistry
- Plant growth and elemental concentrations

Sweet Corn and Soybeans

Study Plan

- 900 grams of soil
- 9 grams of biochar (1% by weight)
- Daily plant growth stage measurements
- Plant locations randomly assigned
- Plants moved on a regular basis
- Plants fertilized
  - NPK for corn
  - Only P& K for soybeans



18 Biochars + Control = 19 Treatments x 6 Replicates = 114 Pots per Crop per Soil
Phase 1 = 2 Crops x 2 soils x 114 Pots = 456 Pots

Lettuce and Carrots

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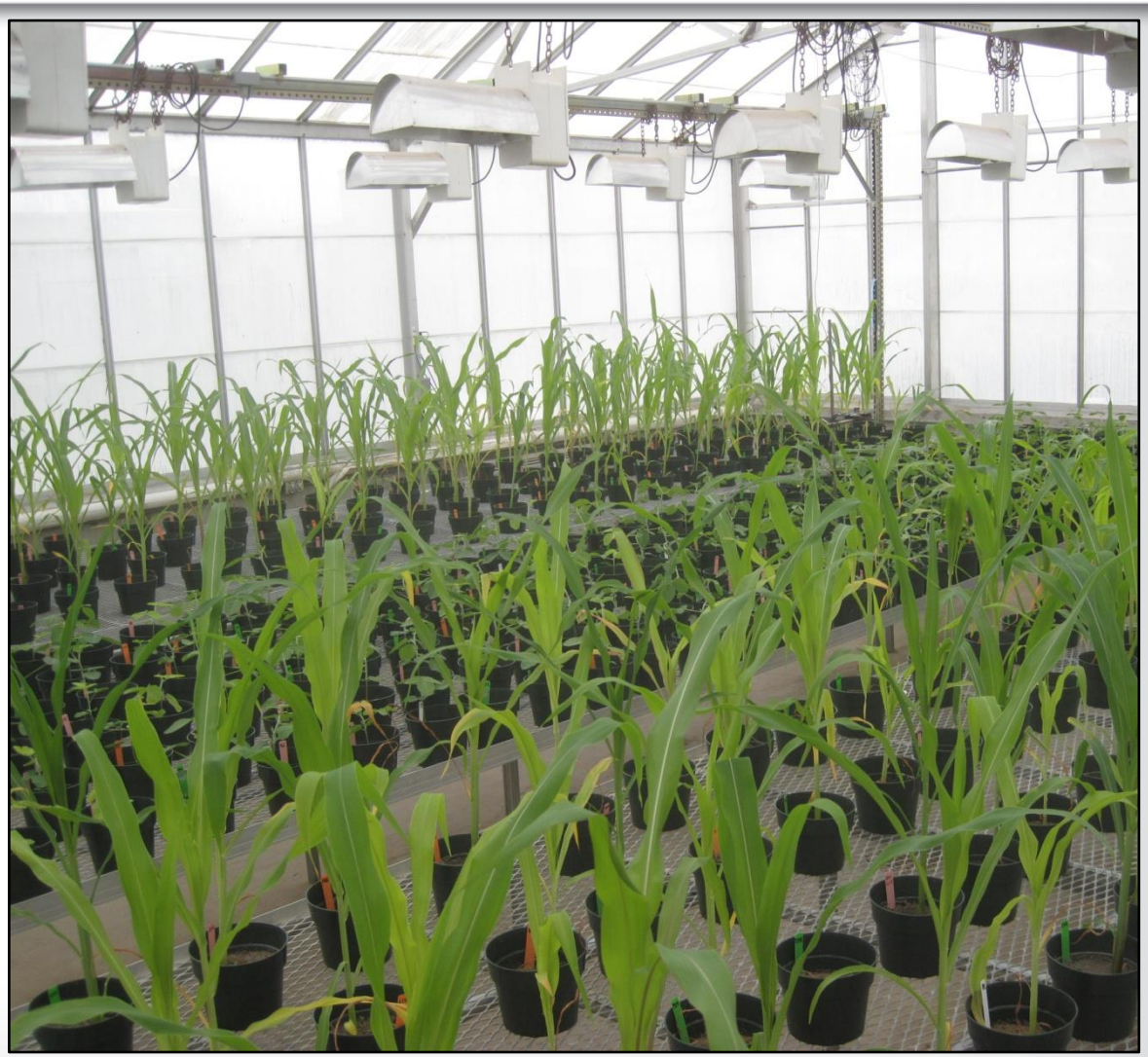

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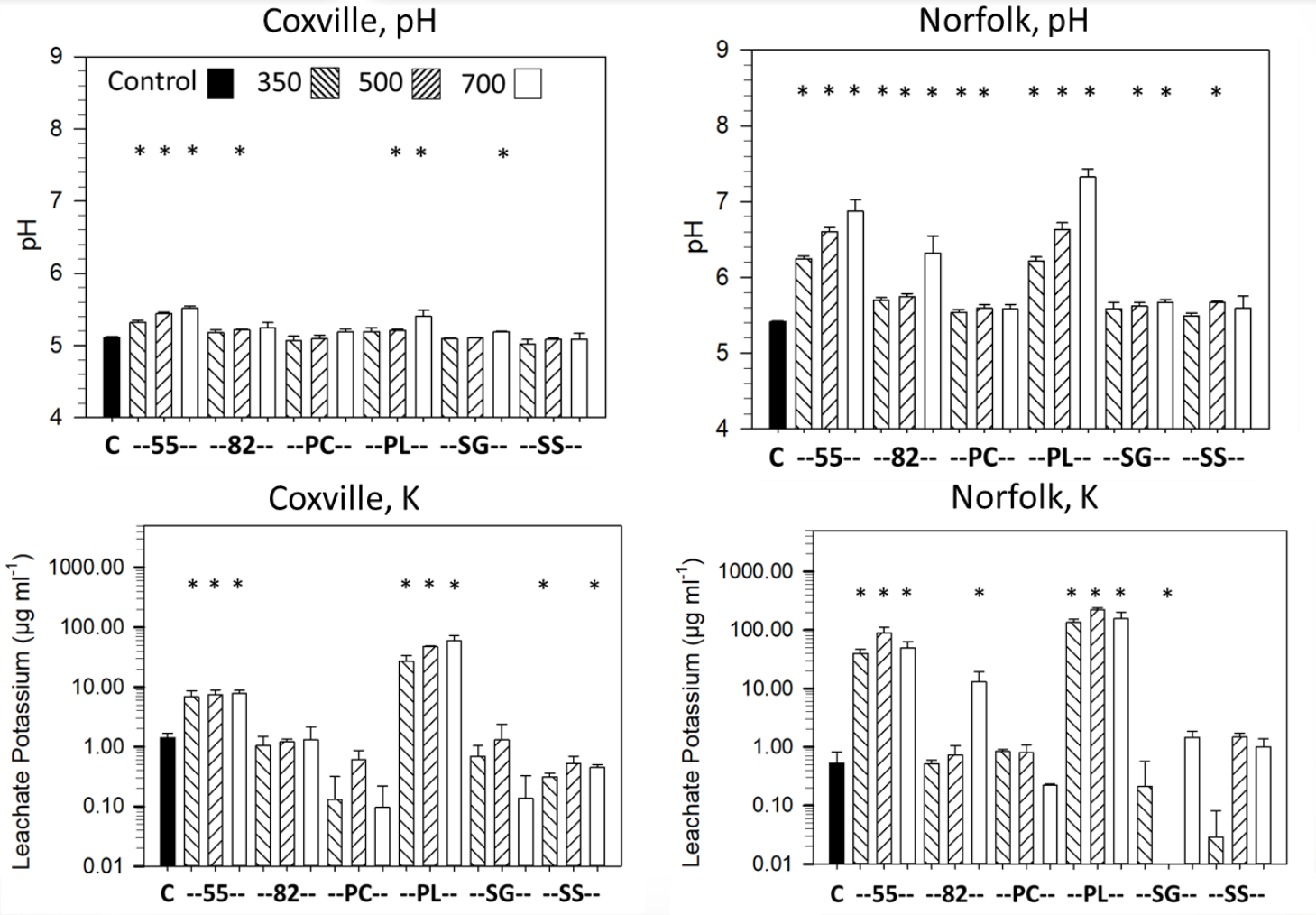
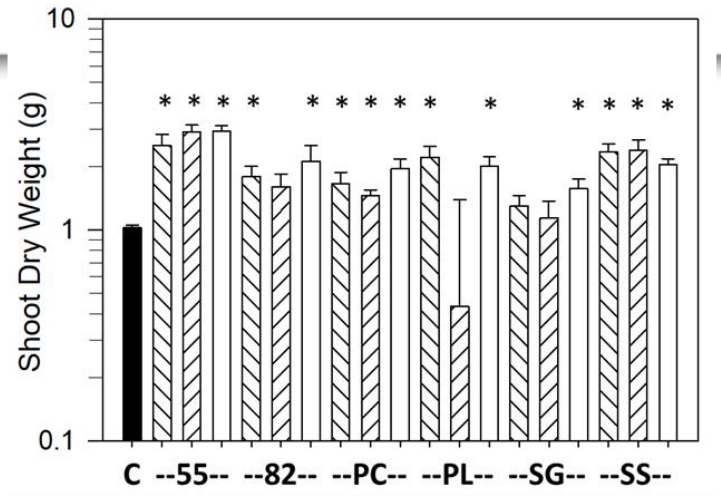
Results: Biochar (Especially Poultry Litter) Increases Soil Leachate pH and Nutrients (K) for Lettuce and Other Crops, Especially for Coarser Norfolk Soil

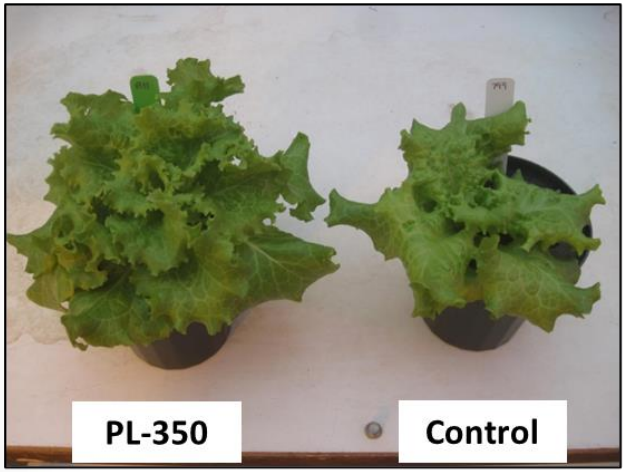


- = Significant increase vs. no biochar control at $p < 0.05$, but some decreases
- PC, pine chips; PL, poultry litter; SG, switchgrass, SS, swine solids; 55, 50% PC/50% PL; 82, 80% PC/20% PL

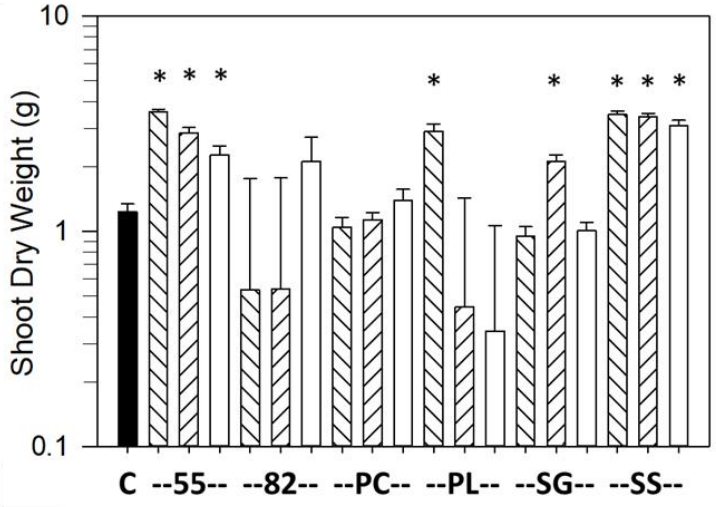
Crop Productivity

Generally Increased, but Depended on Crop, Soil. Biochar Feedstock and Temperature: Lettuce Most Responsive, Soybean Least Responsive, Some Growth Inhibition with PL and high temperatures





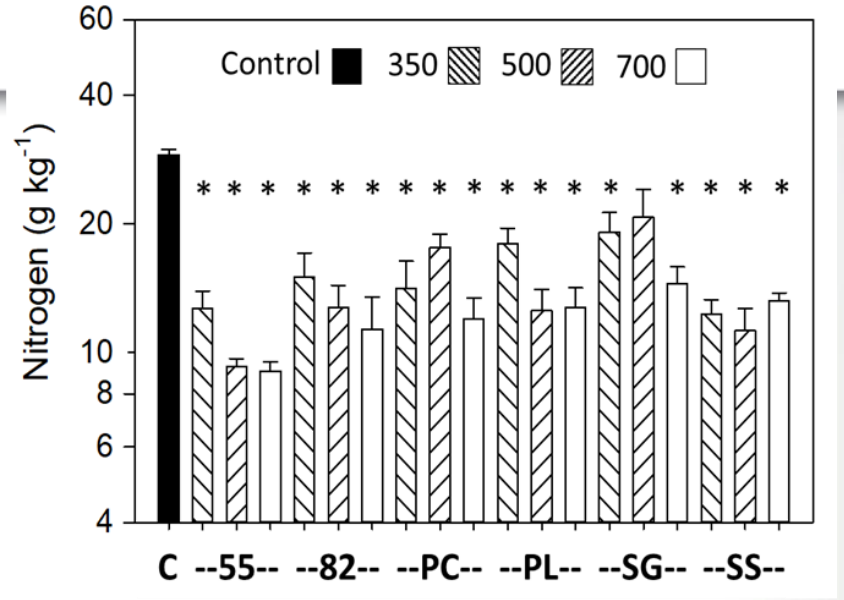
Lettuce in Coxville Soil



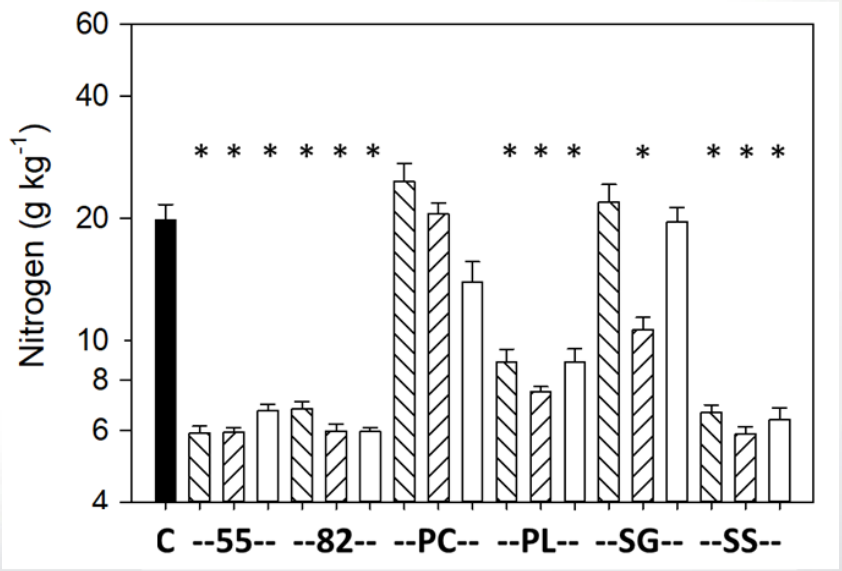
- **= Significant increase vs. no biochar control at p <0.05, especially for finer Coxville soil,**
- **PC, pine chips; PL, poultry litter; SG, switchgrass, SS, swine solids; 55, 50% PC/50% PL; 82, 80% PC/20% PL**

Leaf N Concentration Generally Decreased, Especially Lettuce

- Depended on Crop, Soil, Biochar Feedstock and Temperature
- Decreased more with manure-based biochar, and coarser soil
  - May be related to growth dilution, and fact that plants may have been N limited
- Soybean responded differently N tended to increase



Norfolk



- * = Significant decrease vs. no biochar control at $p < 0.05$
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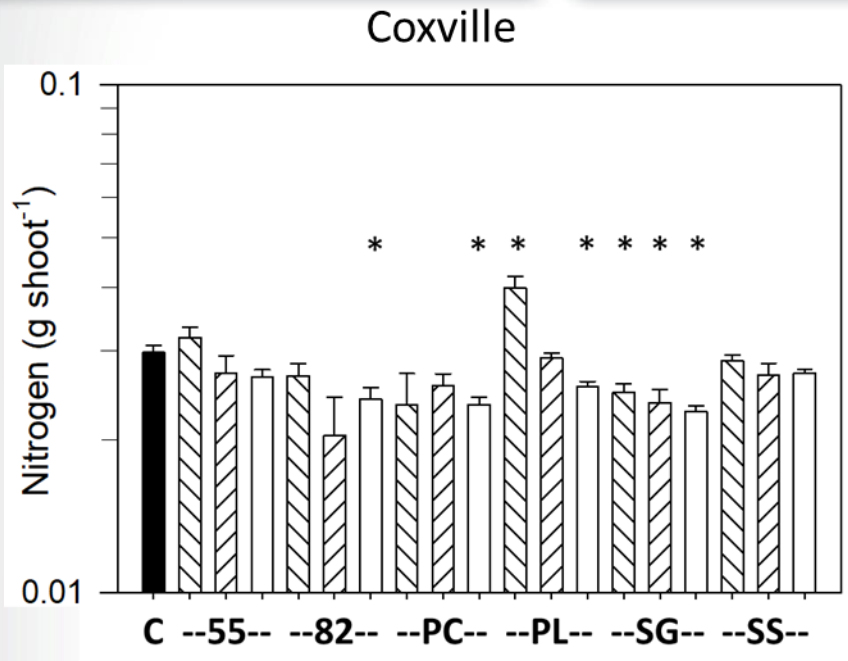
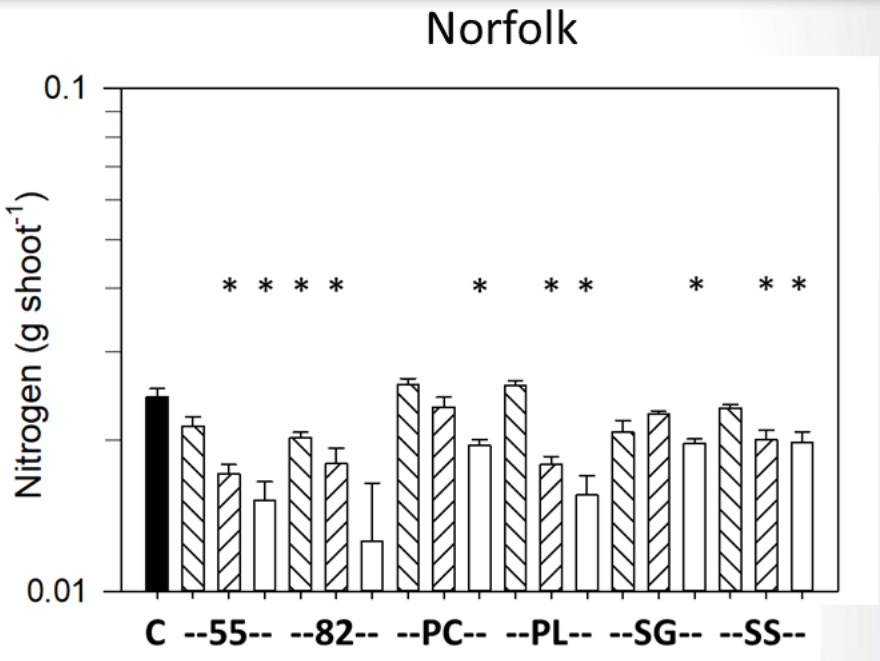
But Leaf N Uptake Not as Much Affected





Depended on Crop, Soil, Biochar Feedstock and Temperature

- * = Significant decrease or increase vs. no biochar control at $p < 0.05$
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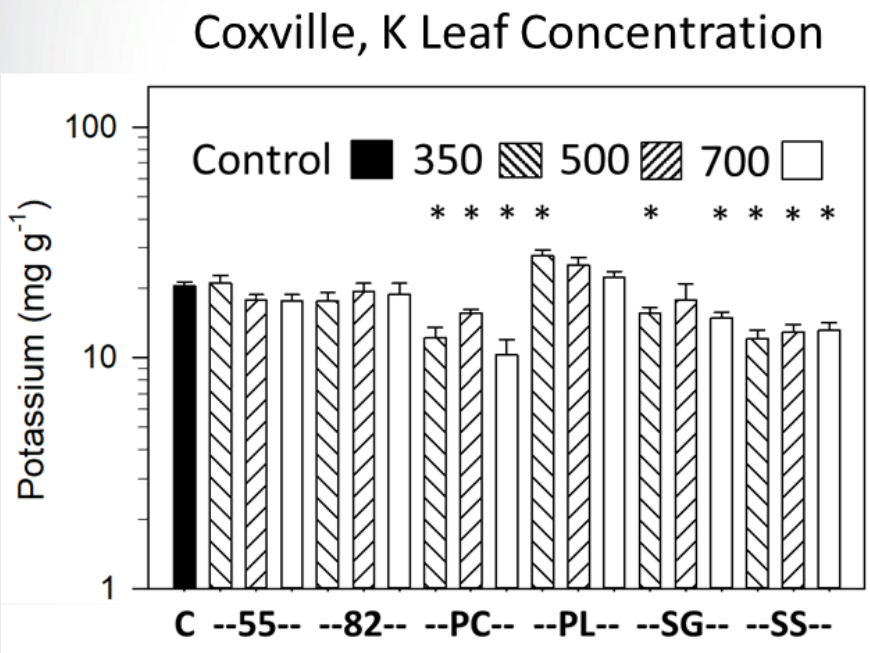
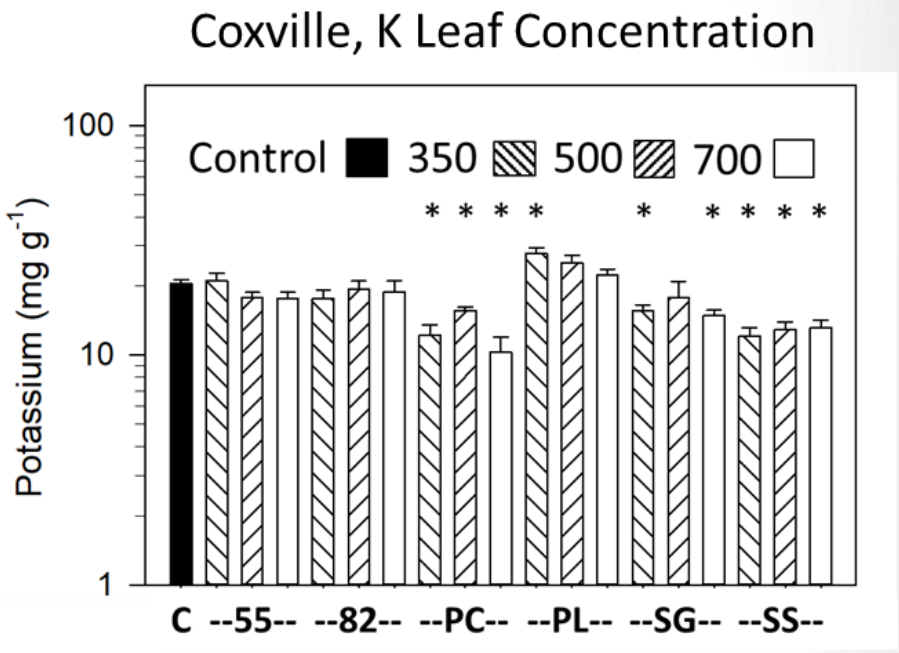
In contrast, leaf K may increase or decrease with Biochar

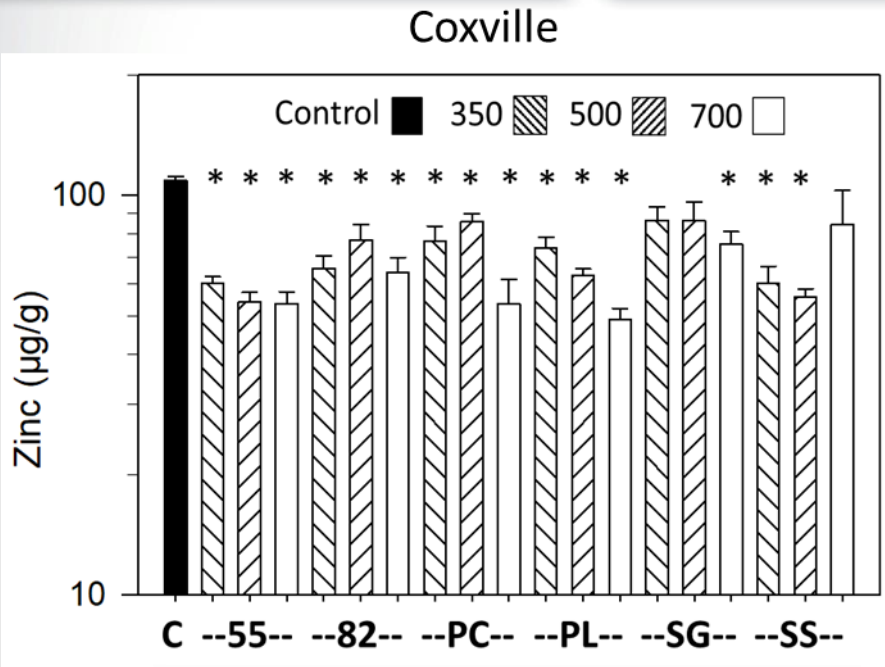


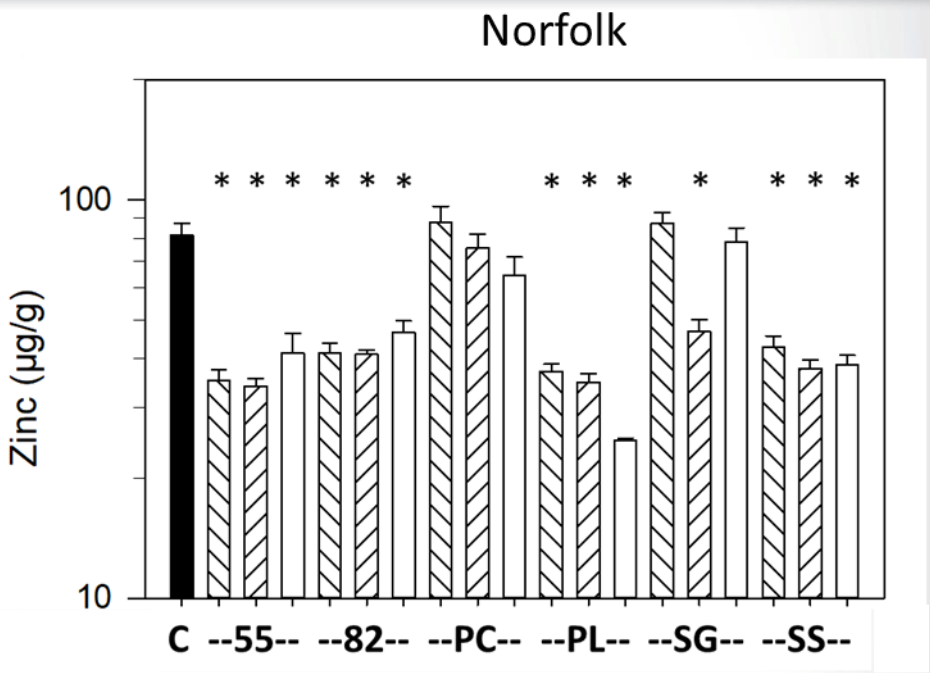


- Depends on Crop, Soil, Biochar Feedstock and Temperature
- Leaf K concentration primarily decreases, but some increases with biochar
- K uptake increases with biochar
- Reflects increase in soil leachate

- * = Significant decrease or increase vs. no biochar control at $p < 0.05$
- PC, pine chips; PL, poultry litter; SG, switchgrass, SS, swine solids; 55, 50% PC/50% PL; 82, 80% PC/20% PL

Other leaf macro (Ca, Mg, P) and micronutrients (Fe, Mn, Zn) generally follow similar pattern as N





- Concentration decreases, especially manure based, (PL and SS) but also some cellulosic treatments (PC and SG)
- Even though uptake may increase
- Could result in deficiencies and reduce plant growth, or reduced nutritive value

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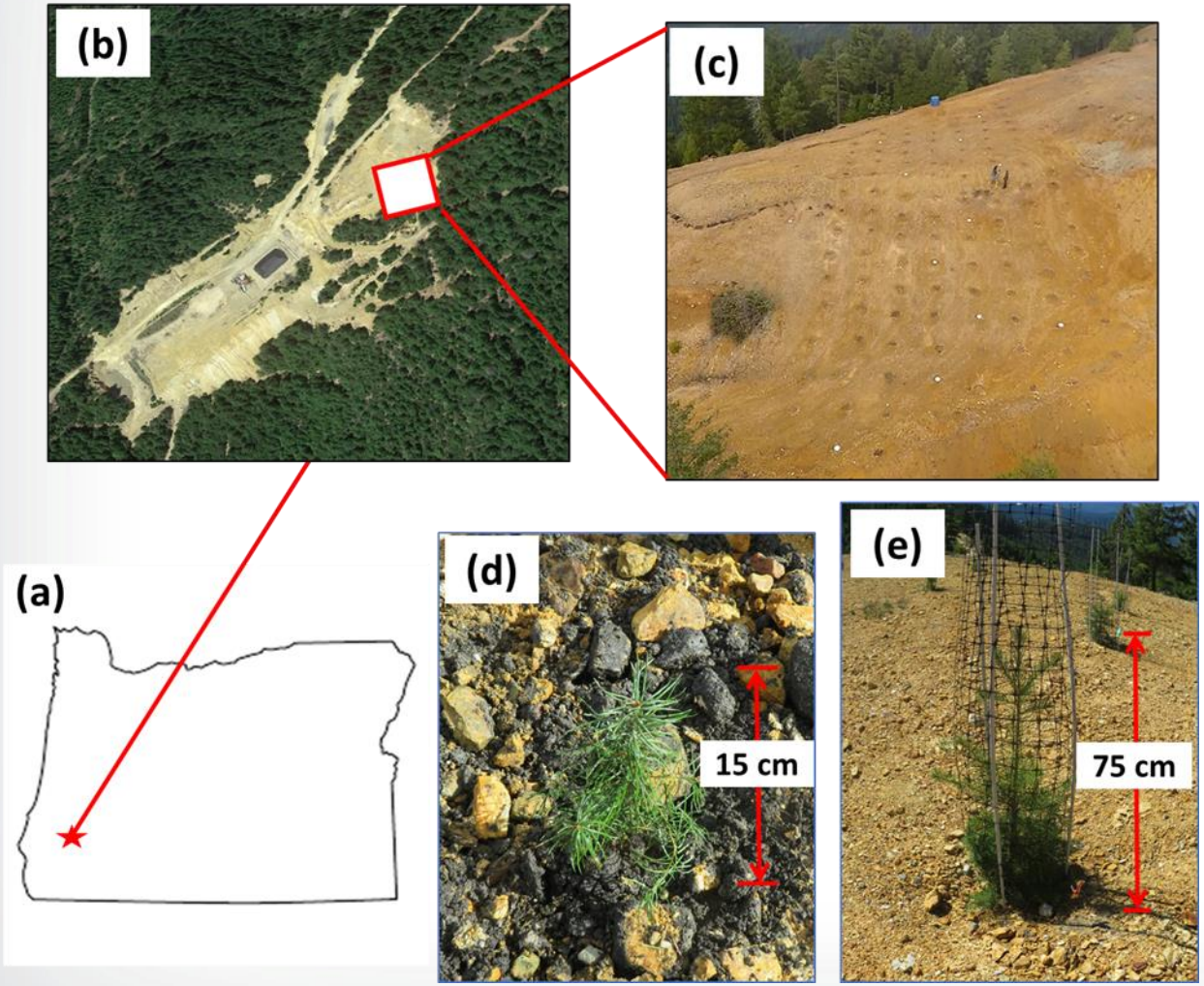
Example of Superfund Research Objectives

- Improve mine tailing chemistry and structure to permit plant growth
  - Increase tailing pH, decrease heavy metal availability, reduce soil bulk density (i.e., soil compaction), improve water holding capacity, add organic material, improve soil quality to promote healthy soil microbial community/biology
  - Phytostabilization, grow plants to prevent soil erosion and water contamination with heavy metals
  - Example: establish trees/vegetation on mine tailings by using biochar, lime, biosolids, and locally effective microbes (LEM) to foster healthy soil microbial community

Superfund Site Remediation: Formosa, OR Site



(a) Approximate location of the Formosa Cu and Zn mine

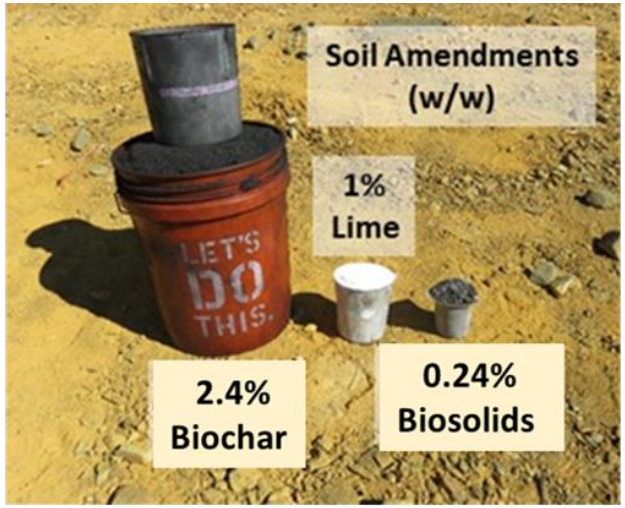
(b) Satellite view of the mine impacted surface

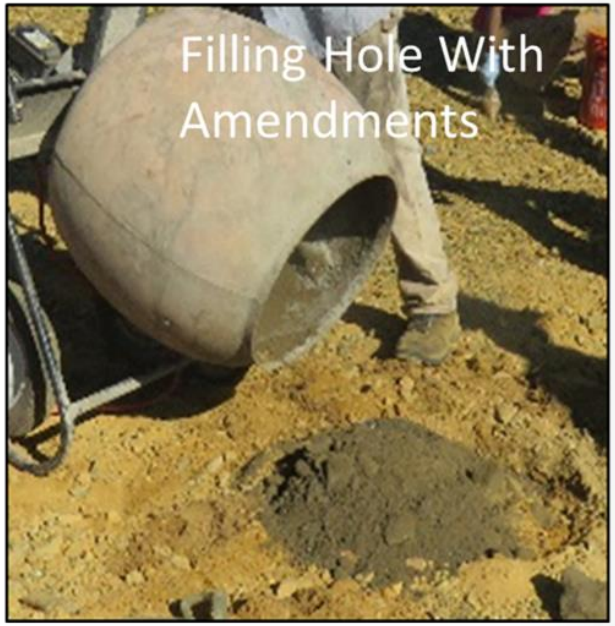
(c) Aerial view of holes before tree planting

(d) Freshly planted Douglas-fir seedling in November 2017

(e) Douglas-fir seedling in October 2019.

Preparing the Formosa Site for Planting Trees





Goal: Establish healthy plants across a degraded landscape

Biochar Conclusions

- Biochar is an effective soil amendment which has the potential to improve crop growth, for degraded soils
  - Increases soil pH, nutrient concentrations, crop biomass
  - Especially coarser soil textures
  - Also, a beneficial use of agricultural waste products

- The feedstock and pyrolysis conditions must be carefully considered ("designer biochar") to provide a biochar which meets a crop nutrient needs
  - Response varies considerable among crops, soils, and biochar type
  - Combinations of manure and cellulosic feedstocks may be most effective
  - Required to counter potential decreases in crop growth with biochar

- Biochar will be most effective when combined with specific, complimentary fertilizer application to offset any reductions in specific nutrients that may occur with specific biochar formulations
  - Especially N, but also possibly Ca, Ma, and trace elements

- Biochar has great potential to promote plant growth on mine tailings, research is continuing

Publications

- Olszyk, D.M., Shiroyama, T., Novak, J.M., Cantrell, K.B., Sigua, G., Watts, D., and M.G. Johnson. 2020. Biochar Affects Essential Nutrients of Carrot Taproots and Lettuce Leaves. HortScience 55:261-271.

- Olszyk, D. Shiroyama, T., Novak, J., Cantrell, K., Sigua, G., Watts, D. and M.G. Johnson. 2020. Biochar affects growth and shoot nitrogen in carrot, lettuce, soybean and sweet corn for 2 soils. Agrosystems, Geosciences and Environment 2020;3:e20067. https://doi.org/10.1002/agg2.20067

- Novak, J.M., Ippolito, J.A., Watts. D.W., Sigua, G.C., Ducey, T.F., and M.G. Johnson. 2019. Biochar compost blends facilitate switchgrass growth in mine soils by reducing Cd and Zn bioavailability. Biochar 1:97-114.

- Novak, J.M., Ippolito, J.A., Ducey, T.F., Watts, D.W., Spokas, K.A., Trippe, K.M., Sigua, G.C. and M.G. Johnson. 2018. Remediation of an acidic mine spoil: Miscanthus biochar and lime amendment affects metal availability, plant growth, and soil enzyme activity. Chemosphere 205:709-718.

Questions?