Biochar to Improve Soils

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http://sunmarkenvironmental.com/bio-char/
Outline

- What is soil, why alter it?
  - Soil Properties
    - Physical
    - Chemical

- What is biochar, why apply it?
  - Biochar Properties
    - Physical
    - Chemical

- What does applying biochar to soil accomplish/not accomplish?
Soil

“The unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants.” SSSA

A soil is characterized by its physical, chemical and biological properties.
Physical Properties

- Texture (Sand/Silt/Clay)
- Pore Size Distribution
- Water Holding Capacity
- Bulk density
- Aggregate Stability
Texture

- % Sand, Silt and Clay
- Influences other soil properties
- Difficult to alter on large scale, possible in smaller settings

http://www.ext.colostate.edu/mg/Gardennotes/214.html
Pore Size Distribution

- Relative percentage of pore space comprised of micro and macro pores
- Influences soils properties such as permeability and infiltration rate

http://nrcca.cals.cornell.edu/soil/CA1/CA1_SoftChalk/CA1_print.html
Water Holding Capacity

- The ability of a soil to retain plant available water
  
  = Amount of water present at field capacity
  - Amount of water present at permanent wilting point
Bulk Density

- \[ \text{Bulk Density} = \frac{\text{weight of soil}}{\text{Volume of soil}} \]
- Measured in g/cm³
- Bulk densities above 1.6 g/cm³ are considered restrictive to root growth
- Compaction increases bulk density
Aggregate Stability

- Soil aggregates are composed of large numbers of soil particles bound together by soil organic matter, biological exudates.
- The ability of aggregates to withstand immersion in water is measured as aggregate stability.

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054302
Chemical Properties

- pH
- Cation Exchange Capacity
- Nutrient Levels
- C/N Ratio
- Organic Matter
- Salinity
pH

- Concentration of H+ ions in soil solution
- Range 0-14
- Maintaining soil in 6.0-6.5 range is ideal for most cropping situations
Cation Exchange Capacity (CEC)

- A soil's ability to hold positively charged ions of mineral nutrients.
- Used as an approximation of soil fertility sometimes.
- Cations exist in equilibrium on the soil exchange sites and in the soil solution.
Nutrient Levels

- Soil test levels of N, P, K and other plant essential elements vary widely.
- Nutrients available below essential levels become limiting.
Carbon/Nitrogen

- C/N ratio can effect the microbial population of a soil
- High levels of carbon can increase microbial populations which in turn tie up nitrogen in unavailable biological forms

http://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1130447040&topicorder=5&maxto=8
Salinity

- Salt content of a soil
- Can be elevated by some human practices such as irrigation, fertilization
- Detrimental to soil structure when predominate salt is sodium
- Inhibits plants ability to absorb water

https://www.ag.ndsu.edu/CarringtonREC/center-points/considerations-for-managing-headland-soil-salinity-and-soil-compaction
What is biochar?

- Terra Preta de Indio
- Can be obtained from a variety of biomass sources
- Formed by pyrolysis, incomplete burning under low oxygen conditions
- Final product is a function of: Pyrolysis Temperature and Rate as well as biomass origin

http://biochar.ucdavis.edu/
Biomass is dried, excess water removed

Biomass ground in some cases in order to increase SA and produce more consistent pyrolysis rates

Biomass is then burned between 300 and 900 degrees Celsius in oxygen deprived environment

Kilns/Furnaces/Ovens

http://www.biochar-international.org/BEC

Large scale Production

http://www.biochar-international.org/carbon_roots_international
How the amendment is incorporated

- Lime Spreader followed by Disking
- Deep Banding
- Manure Spreader
- Hand Application

http://www.biocharapplication.com/methods-to-date.html
Does it Matter what the Biomass Source is, What about soil Type?

- Factors such as biochar type, production method, soil type and plant type are known to cause variation in effects on soil.
- Ex. Hardwood vs. Crop Residue
- Fast vs. Slow Pyrolysis
- Tropical Weathered Soils vs. Midwest United States Soil
Ways in which biochar varies

- Carbon, Hydrogen, Nitrogen and Sulfur content
- Trace Metal content
- pH
- Surface area/structure
- Bulk Density
- Water Holding Capacity
- Thermal decomposition

http://www.biochar-international.org/projects/book
## Carbon/Hydrogen/Nitrogen/Sulfur

<table>
<thead>
<tr>
<th></th>
<th>Carbon</th>
<th>Hydrogen</th>
<th>Nitrogen</th>
<th>Sulfur</th>
<th>C:N</th>
<th>C:H</th>
<th>C:S</th>
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</thead>
<tbody>
<tr>
<td><strong>Corn</strong></td>
<td>53.26b</td>
<td>1.96c</td>
<td>0.98a</td>
<td>0.78b</td>
<td>54.35</td>
<td>27.22</td>
<td>68.28</td>
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<tr>
<td><strong>Miscanthus</strong></td>
<td>73.10a</td>
<td>2.32b</td>
<td>0.39c</td>
<td>0.75b</td>
<td>189.06</td>
<td>31.51</td>
<td>97.04</td>
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<tr>
<td><strong>Horse Manure</strong></td>
<td>13.04c</td>
<td>0.59d</td>
<td>0.42b</td>
<td>0.31c</td>
<td>31.04</td>
<td>22.10</td>
<td>42.05</td>
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<tr>
<td><strong>Hardwood</strong></td>
<td>65.47a</td>
<td>3.97a</td>
<td>1.05a</td>
<td>1.07a</td>
<td>62.15</td>
<td>16.50</td>
<td>60.99</td>
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</tbody>
</table>
### ICP-OES

#### Raw Material Trace Metal Concentration (ppm)

<table>
<thead>
<tr>
<th>Sample</th>
<th>$Al$</th>
<th>$Ca$</th>
<th>$Cu$</th>
<th>$Fe$</th>
<th>$Mg$</th>
<th>$Mn$</th>
<th>$Na$</th>
<th>$Si$</th>
<th>$Zn$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>870.93(b)</td>
<td>4926.99(b)</td>
<td>41.68(a)</td>
<td>676.22(c)</td>
<td>1341.17(b)</td>
<td>28.91(c)</td>
<td>440.12(b)</td>
<td>228.73(a)</td>
<td>64.85(a)</td>
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<tr>
<td>Miscanthus</td>
<td>174.31(c)</td>
<td>1693.02(b)</td>
<td>27.69(b)</td>
<td>1134.47(b)</td>
<td>635.62(b)</td>
<td>165.46(b)</td>
<td>196.49(c)</td>
<td>112.38(b)</td>
<td>23.30(a)</td>
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<tr>
<td>Horse Manure</td>
<td>3911.98(a)</td>
<td>11355.62(a)</td>
<td>16.97(c)</td>
<td>3228.73(a)</td>
<td>4249.37(a)</td>
<td>224.86(a)</td>
<td>1177.72(a)</td>
<td>297.47(a)</td>
<td>61.13(a)</td>
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<tr>
<td>Hardwood</td>
<td>25.62(c)</td>
<td>2988.01(b)</td>
<td>43.079(a)</td>
<td>60.11(d)</td>
<td>357.34(b)</td>
<td>25.59(c)</td>
<td>439.81(b)</td>
<td>92.95(b)</td>
<td>2.58(a)</td>
</tr>
</tbody>
</table>
## ICP-OES

### Biochar Trace Metal Concentration (ppm)

<table>
<thead>
<tr>
<th>Element</th>
<th>Corn</th>
<th>Miscanthus</th>
<th>Horse Manure</th>
<th>Hardwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>136.07(b)</td>
<td>151.73(b)</td>
<td>12212.08(a)</td>
<td>166.98(b)</td>
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<tr>
<td>Ca</td>
<td>10185.75(b)</td>
<td>2539.31(c)</td>
<td>9074.13(b)</td>
<td>20915.33(a)</td>
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<tr>
<td>Cu</td>
<td>ND</td>
<td>ND</td>
<td>18.91</td>
<td>ND</td>
</tr>
<tr>
<td>Fe</td>
<td>136.04(b)</td>
<td>239.02(b)</td>
<td>20454.87(a)</td>
<td>378.40(b)</td>
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<tr>
<td>Mg</td>
<td>4648.02(a)</td>
<td>660.97(c)</td>
<td>3444.35(b)</td>
<td>1091.62(c)</td>
</tr>
<tr>
<td>Mn</td>
<td>128.87(d)</td>
<td>285.13(b)</td>
<td>752.95(a)</td>
<td>180.22(c)</td>
</tr>
<tr>
<td>Na</td>
<td>149.78(b)</td>
<td>121.54(b)</td>
<td>1065.28(a)</td>
<td>81.63(b)</td>
</tr>
<tr>
<td>Si</td>
<td>201.36(a)</td>
<td>260.41(a)</td>
<td>221.57(a)</td>
<td>358.99(a)</td>
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<tr>
<td>Zn</td>
<td>62.48(b)</td>
<td>ND</td>
<td>142.60(a)</td>
<td>16.88(c)</td>
</tr>
</tbody>
</table>
pH

Biochar pH

- Miscanthus
- Corn Stover
- Horse Manure
- Hardwood

Legend:
- a
- ab
- bc
- c

pH
Surface Area

SEM Photography
Corn
Horse Manure
Miscanthus
Hardwood
X-Ray Diffraction

X-ray diffraction profiles (CuK radiation) of the four biochars. Sharp non-labeled peaks are from inorganic components. Vertical lines denote peaks assigned to cellulosic crystallinity.
Bulk Density

[Bar chart showing biochar bulk density for Horse Manure, Miscanthus, Hardwood, and Corn Stover.]
Water Holding Capacity

Biochar WHC by Type

- **Corn Stover**: a
- **Miscanthus**: b
- **Horse Manure**: bc
- **Hardwood**: c

Bars represent WHC (%) for different biochar types.
Thermo gravimetric Analysis

![TGA Raw Materials Graph](image-url)
Thermo Gravimetric Analysis

![Graph showing Thermo Gravimetric Analysis](image)

- **Weight (%)**
- **Temperature (°C)**

Legend:
- Corn-bio
- Hardwood-bio
- Horsemanure-bio
- Miscanthus-bio
Problem Statements

- Can biochar be used to change soil chemical, physical and biological properties?
- What are some soil properties we would want to alter, why?
What Soil Properties Would We Want to Alter?

- Low water holding capacity and conversely low infiltration rates
- Aggregate Stability
- CEC extremes
- pH extremes
- Soil OM
- High Bulk Density
- Nutrient Content/availability
- Salinity
Biochar effects

Applications of biochar have been shown to alter soil physical qualities such as water holding capacity, pore size, nutrient availability, and bulk density (Downie et al., 2009), and chemical properties such as pH, CEC, nutrient status, and organic matter. Some indication of soil salinity reduction has been observed as well (Lashari et al., 2012).
How does it do this?

- Biochar generally has an alkaline or basic pH, its addition to a soil will increase the pH of the soil water solution.

- The large surface area and charge concentration on the surface of biochars result in a high CEC.

- Soil particle aggregation. Biochars have been shown in some instances to perform a similar function to other forms of organic matter in causing aggregation.
Biochar has been shown to have a generally positive impact on crop growth in many cases, but results have varied widely across different soil types and amendment regimens (Major et al 2010, Chan et al. 2007, Glaser et al. 2002).
Biochar Effects Continued

- A review of 46 studies where yield or growth rate was measured in relation to biochar application, (Spokas et al, 2012) found that approximately 50% of the compiled studies observed short-term positive yield or growth impacts, 30% reported no significant differences, and 20% noted negative yield or growth impacts.

- Typically highly degraded soils respond the most to biochar applications. Some doubt about effects on soils that are already relatively fertile.
Potential Drawbacks

- Many unknowns
- Toxic compounds
- Persistence, once it's there impossible to remove
- Application costs/What is a meaningful amount to apply?
- Efficacy on varying soil types
- Biomass source?
  - Hydrophobic qualities of some biochars, ex. Hardwoods.
Conclusions

- Biochar does alter soil properties.
- The specific alterations and their magnitude are dependent on the physical and chemical characteristics of the biochar itself, the physical and chemical characteristics of the soil to which it is applied, and the amount of biochar material applied.
- It is not a cure all, research changes perceptions of its effectiveness and feasibility year to year.
- There is credible research that has determined it to be beneficial in some situations, and a large amount of anecdotal information about it.