C – Biochar as a soil amendment treatment for restoring forest stands

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As a soil amendment, biochar is useful for sequestering carbon, with other benefits related to its physical structure that increases the retention of H_2O and water-soluble nutrients while reducing soil acidity and nutrient leaching. Biochar treatments can directly impact plant health and may improve habitat for beneficial microorganisms. However, application of biochar can also result in shifts in soil microbial communities. Some insects show delayed development, decreased fecundity, lowered egg hatch and increased mortality when exposed to biochar under various application conditions. Such effects require further examination. The session was set up to introduce participants to the uses of biochar in forest systems as well as the potential impacts (both direct and indirect) on soil properties and the biological communities that occur in the application area.

Impact of biochar on soil physical, chemical, and biological properties

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Abstract
Restoring or enhancing soil properties on forest, range, mine, or agricultural soils is becoming increasingly important. In particular, threats to soil from drought, intense rain, flooding, heat, and wildfire can reduce the productive capacity of the soil and also reduce our ability to grow food and fiber or regulate carbon (C), water, or nutrients (Blanco-Canqui 2021). Creating wood-based biochars from material normally burned in slash piles is an opportunity to increase forest health by decreasing wildfire risk or insect and disease outbreaks (Rodriguez-Franco and Page-Dumroese 2021). Forest restoration efforts to reduce stand stocking is common on public lands, but there is often no end use for limbs, branches, cull sections, or unmerchantable round wood (Anderson et al. 2016). However, biochar made from this 'waste' wood is one way to increase woody residue values while also improving forest stand conditions (Bergman et al. 2016), improving soil conditions, and mitigating climate change. Biochar is a high C (25-95% C) substrate and its addition to soil can rapidly increase soil C levels (Blanco-Canqui et al. 2020; Liu et al. 2016) depending on soil type, biochar feedstock, application rates, and conditions under which biochar is created. Further, creation of biochar using mobile pyrolysis units, kilns, or carefully built slash piles (Page-Dumroese et al. 2017) at log landings or on skid trails reduces transportation costs while creating biochar on-site.

Soil Changes
Physical properties: Biochar is highly porous and therefore using it on organic matter-degraded soil or those that are compacted has many advantages. It can improve soil porosity, pore-size distribution, bulk density, moisture holding capacity, infiltration, and hydraulic conductivity (Atkinson et al. 2010; van Zwieten et al. 2012). It is important to note that different soil

taxonomic classes will respond differently to char additions (Table 1). This change in water relations, however, could be extremely helpful for restoring log landings and skid trails within harvest units. Adding biochar can also help form soil micro-aggregates (Verheijen et al. 2009) and increase vegetation establishment (Adams et al. 2013). Biochar can prevent the surface soil from sealing and thereby reduce sedimentation and runoff (Luce 1997). By changing soil physical properties, biochar may also increase forest health. For example, amending silt loam soils with 10% biochar made from lignocellulose increased plant water use efficiency of pine-oak forest understory plants (Licht and Smith 2018). One important change in soil physical properties associated with biochar addition is the increased potential for storing water. The addition of 1% organic matter or biochar can increase water storage in the soil by 1-3% (Libhova et al. 2018) and this can be particularly important on coarse-textured soils (Basso et al. 2013).

Table 1. Soil moisture content changes associated with biochar additions in two soil taxonomic classes (after Page-Dumroese et al. 2016. Chapter 15).

Taxonomic Order	Biochar Addition ---- $v\ v^{-1}$ ----	Soil Moisture ---- $w\ w^{-1}$ ----
Andisol	0	0.38
	12	0.40
	25	0.43
	50	0.47
Mollisol	0	0.18
	12	0.21
	25	0.25
	50	0.28

Importantly, biochar can increase plant available water by 38% in coarse-textured soil, 19% in medium-textured soil, and 16% in fine-textured soils (Blanco-Canqui 2017, Edeh et al. 2020, Razzaghi et al. 2021) and highlights the importance of using biochar on coarser-textured soils. Understanding how much plant available water that results from biochar applications should be assessed for each soil and biochar type (Atkinson 2018).

Chemical properties: Soil chemical changes associated with biochar additions are dependent on the type, quality, and quantity of biochar applied. Most biochars tend to be alkaline (pH >6.0) and can act as a liming agent in acidic soils (Glaser et al. 2002, Xu et al. 2014). It has also been shown to increase cation exchange capacity and, because of the increase in exchange sites, it can reduce nutrient leaching through the soil profile (Ducey et al. 2013). As the biochar ages within the soil these properties may change and are dependent on soil, climatic regime, biochar feedstock, and pyrolysis conditions.

Biological properties: Biochar is incredibly porous and therefore provides great habitat for soil microbial communities. It can also stimulate both nitrification and denitrification processes and reduce N_2O emissions (Xu et al. 2014). Soil microbial community composition and function may also change in forest soils as a result of biochar additions. Early work noted that biochar is particularly beneficial for fungi (Warnock et al. 2007), but more recent work has also shown that bacterial populations and an the bacterial:fungi ratio may also be increased (Gomez et al. 2014).

Biochar and Forest Health: Increasing soil health by using biochar can also improve forest health by making vegetation more resilient to drought and a changing climate. Increased soil health can also mean that trees are less susceptible to insect or disease attack or better able to withstand infestations because of a change in soil water holding capacity and available water. In addition, because of the changes in C, nutrients, and microbial communities, biochar has been shown to reduce disease severity of several different pathogens. Although most of the work has been done on agricultural crops (e.g., Elad et al. 2010, Elmer and Pignatello 2011) the defense-enhancing mechanisms of biochar may also be important for forest vegetation since these sites are often low in organic matter and nutrients and biochar can improve nutrient retention and water holding-capacity.

Biochar is a rapid method for increasing soil C and it also imparts other benefits such as increase water holding, reduced leaching, or altering soil microbial communities. In addition, on many degraded sites (e.g. skid trails, log landings) biochar can increase soil cover; thereby reducing the potential for wind and water erosion. The key to successful deployment of biochar, however, is to understand the type of biochar, soil, and climatic regime. Usually, degraded soils have a greater response than soils with a high organic matter content, but many soils benefit from biochar additions and the ecosystem benefits can be even greater (Blanco-Canqui 2021).

Keywords: soil health, forest health, forest restoration

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