Biochar Application Effects on Temperate Forest Soil Properties

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Introduction

Bioenergy production from forest biomass offers a potential solution to reduce wildfire hazard fuel. However, removing biomass can reduce the formation of soil organic carbon and may have negative impacts on soil fertility. Portable pyrolysis technology uses biomass to generate biofuels and a carbon-rich, biochar product that can be used as a soil amendment and is resistant to decomposition. Biochar application can increase soil organic carbon and retain nutrients on forest sites. Excess forest biomass could be used to produce biofuels through pyrolysis while reducing wildfire risk, and the biochar byproduct used to sequester carbon and improve soil quality. Several studies indicate biochar can enhance soil productivity in agricultural systems by increasing cation exchange capacity and nutrient status (Laird 2008; Lehmann et al. 2006; Sohi et al. 2010). However, existing research has not adequately described effects of biochar amendments to temperate forest soils. It is essential that we understand the effects of biochar among soil types, vegetative communities, climatic regions, and various ecosystems before biochar is deployed on a large scale or used as a viable amelioration tool for land managers.

Objectives:
This research is meant to evaluate environmental implications of applying biochar to temperate forests. In particular, we investigated the influence of biochar additions and application methods on chemical properties of various soils of Idaho.

Materials & Methods

Biochar:

Fast pyrolysis CQuest™ biochar produced by Dynamotive Energy Systems
Particle size <1 mm; pH~7, ash content 10.85%; C 72.48 (%-wt/wt); N 0.45%;
C:N ratio 161:1 (Dynamotive Energy Systems Corporation, Richmond BC, Canada)

Figure 1. Dynamotive Energy CQuest ™ Biochar
http://www.biocharapplication.com/types-of-biochar.html

Soil:

Table 1: Soil type, location, and horizon of collection

Soil	Classification	Horizon	Location
Forest Andisol	medial over loamy, mixed, frigid Alfic Udivitrand	Bw	Clearwater County, ID
Forest Spodosol	sandy, mixed, frigid Aquic Haplorthod	E	Priest Lake, ID
Agricultural Mollisol	fine-silty, mixed, superactive, mesic Pachic Ultic Haploxeroll	Ap	Moscow, Idaho

Note: All soils were collected from the upper 20 cm of the mineral soil, excluding the Spodosol which was only collected from the E horizon.

Figure 2. From left to right: forest Andisol, forest Spodosol, agricultural Mollisol

- After collection, all soil was air-dried and sieved to 2 mm

Column & Treatment Preparation:

- Columns: open-top, 10-cm-diameter, 17-cm tall, schedule-40 PVC
- Bottoms closed using 20-mesh nylon screens to support the soil
- Treatments: Each treatment was replicated six times for a total of 54 soil columns

  - Control: Soil was poured into columns and tapped on a laboratory bench to obtain field bulk densities
  - Surface: 25 Mg ha^{-1} biochar applied to the surface of soil columns. Treatment meant to imitate top-dressed application of biochar—realistic for forest systems
  - Mixed: 25 Mg ha^{-1} biochar incorporated throughout the soil column. Treatment meant to imitate tilling in agricultural systems. Soil was poured into columns and tapped on a laboratory bench to obtain adjusted field bulk densities that accounted for reductions due to biochar incorporation

- A 2.5cm deep litter layer was included in the forest soil treatments to imitate natural field conditions There was no litter present in the Mollisol.
- Cores were irrigated weekly to field capacity with a .01M solution of CaCl to imitate rainwater water and incubated for 30 weeks

Figure 3. Column preparation and surface treatment example

Measurements & Data Analysis:

- Cores destructively sampled and analyzed for:
  Available K & P (Na Acetate Extraction), Total C & N (Combustion), Cation Exchange , Capacity (Ammonium Acetate, FIA), Calcium, Potassium, Magnesium, Sodium (NH4 Acetate Extraction, ICP), Nitrate-N + Nitrite-N, Nitrogen-Ammonia (KCl Extractable, Colorimetric), Organic Matter (Dichromate/H2SO4,Colorimetric), and pH (saturated paste, Electrode)
- Soil analyses were conducted at the Analytical Sciences Laboratory, Moscow, ID.
- Data analyzed using analysis of variance and least squares means separation procedure followed by the Tukey's post hoc procedure (SAS Institute Inc, 2008). Statistical significance assigned at the p ≤ 0.05 level.

Results

Table 1: *ANOVA* table

Source	DF	pH	CEC	Ca	Mg	K	Na	Base Saturation %	Available P (ug/g)	Available K (ug/g)	$NO_3 + NO_2$ (µg/g)	NH_4^+ (ug/g)	Organic Matter %	Total C %	Total N %
Treatment	2	0.029	0.025	0.554	0.532	0.000	0.220	0.658	0.382	<.0001	0.941	0.006	0.022	<.0001	0.172
Soil	2	<.0001	<.0001	<.0001	<.0001	<.0001	0.379	0.056	<.0001	<.0001	0.010	<.0001	<.0001	<.0001	<.0001
Treatment*Soil	4	0.028	0.289	0.549	0.701	0.024	0.647	0.468	0.133	0.140	0.891	0.003	0.543	0.012	0.302

Note: Significant at the p<0.05 value. CEC, Ca, Mg, K, and Na units are cmol kg-1

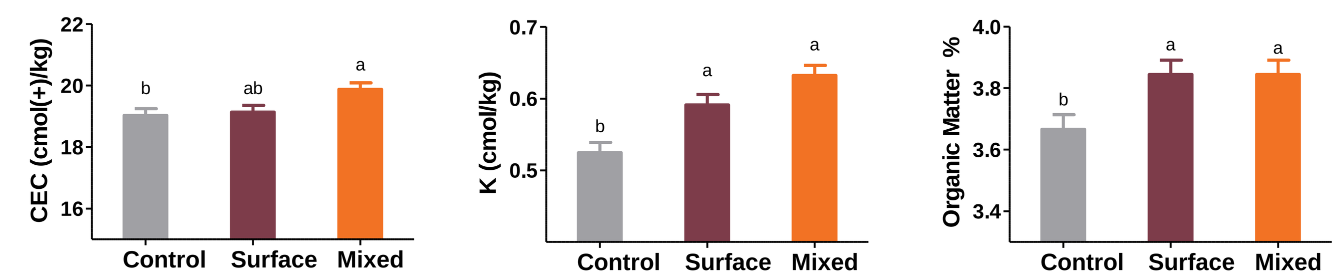

Figure 4. Treatment effects observed in CEC, K, and OM at 30 weeks. Letters denote significant differences at P<0.05.

- The mixed treatment significantly increased CEC by 5% relative to the control.
- Both the surface and mixed treatment significantly increased K by 14% and 22%, respectively.
- Both the surface and mixed treatment significantly increased OM by 7%.

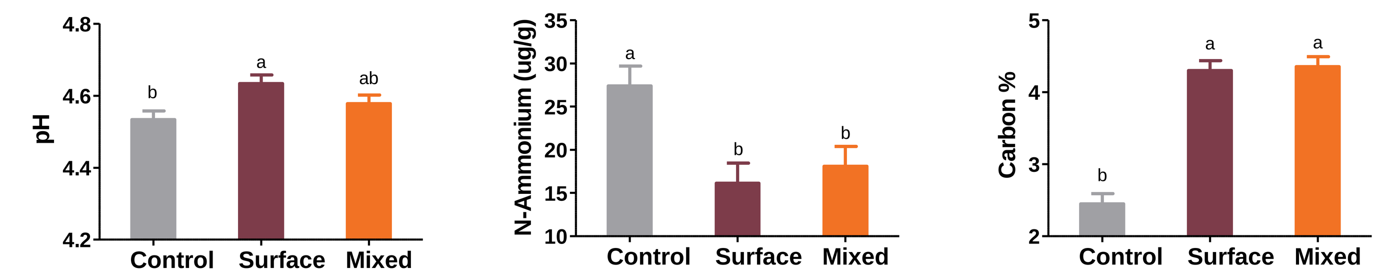

Figure 5. Treatment effects observed in pH, NH_4, and C at 30 weeks. Letters denote significant differences at P<0.05.

- The surface treatment significantly increased pH by 3% relative to the control.
- Both the surface and mixed treatment significantly decreased NH_4 by 42% and 34%, respectively.
- Both the surface and mixed treatment significantly increased C by 79% and 83%, respectively.

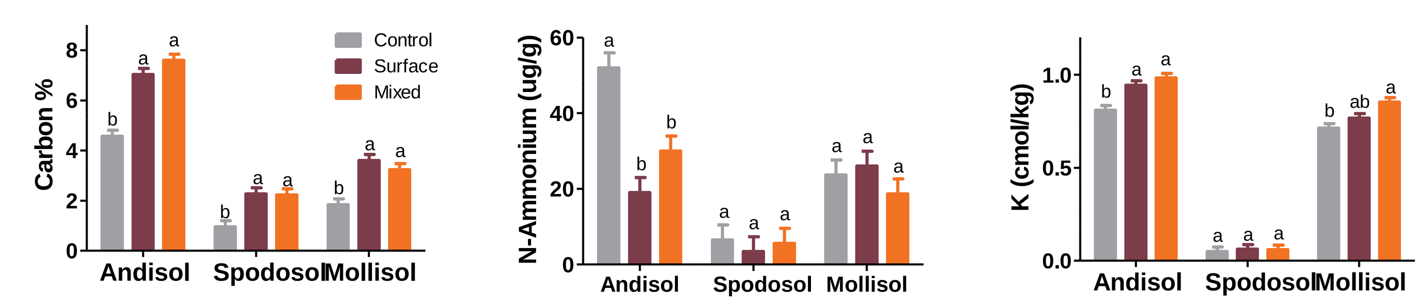

Figure 6. Treatment*soil interaction effects observed in C, NH_4, and K at 30 weeks. Letters denote significant differences at P<0.05 between treatments within soil types.

- The surface treatment significantly increased C in all soil types.
- Both the surface and mixed treatment significantly decreased NH_4 in the Andisol only.
- Biochar treatments had no effect on K in the Spodosol.

Table 2: Analysis of C, N, OM and nutrients in soil at 30 weeks

	Andisol			Spodosol			Mollisol		
Biochar Treatment (25 Mg/ha)	Control	Surface	Mixed	Control	Surface	Mixed	Control	Surface	Mixed
pH	5.33 ± 0.1	5.33 ± 0.0	5.40 ± 0.0	3.87 ± 0.0	4.10 ± 0.0	4.0 ± 0.06	4.40 ± 0.1	4.47 ± 0.0	4.33 ± 0.0
CEC (cmol kg-1)	31.67 ± 0.8	31.0 ± 0.0	32.33 ± 0.3	5.43 ± 0.1	6.43 ± 0.44	6.63 ± 0.22	20.00 ± 0.0	20.0 ± 0.0	20.67 ± 0.3
Base Saturation (%)	56.27 ± 2.8	61.81 ± 1.3	57.45 ± 2.2	61.29 ± 9.7	47.46 ± 4.5	54.56 ± 5.7	65.93 ± 7.6	62.57 ± 1.8	68.17 ± 5.5
OM (%)	6.67 ± 0.1	7.0 ± 0.0	6.97 ± 0.1	1.37 ± 0.1	1.43 ± 0.1	1.47 ± 0.1	2.97 ± 0.0	3.10 ± 0.1	3.10 ± 0.0
Total C (%)	4.57 ± 0.2	7.03 ± 0.4	7.60 ± 0.3	0.95 ± 0.1	2.26 ± 0.2	2.23 ± 0.4	1.83 ± 0.0	3.60 ± 0.2	3.23 ± 0.1
Total N (%)	0.17 ± 0.0	0.18 ± 0.0	0.18 ± 0.0	0.05 ± 0.0	0.05 ± 0.0	0.05 ± 0.0	0.14 ± 0.0	0.16 ± 0.0	0.14 ± 0.0
K (cmol kg-1)	0.81 ± 0.0	0.94 ± 0.0	0.98 ± 0.0	0.05 ± 0.0	0.06 ± 0.0	0.06 ± 0.0	0.71 ± 0.1	0.77 ± 0.0	0.85 ± 0.0
Ca (cmol kg-1)	16.0 ± 0.6	17.33 ± 0.3	16.67 ± 0.7	3.03 ± 0.6	2.70 ± 0.1	3.33 ± 0.5	11.0 ± 1.0	10.67 ± 0.3	11.67 ± 0.8
Mg (cmol kg-1)	0.85 ± 0.0	0.79 ± 0.1	0.81 ± 0.1	0.16 ± 0.0	0.16 ± 0.0	0.16 ± 0.0	1.35 ± 0.5	0.99 ± 0.1	1.47 ± 0.3
Na (cmol kg-1)	0.12 ± 0.0	0.09 ± 0.0	0.11 ± 0.0	0.09 ± 0.0	0.09 ± 0.0	0.09 ± 0.0	0.13 ± 0.0	0.09 ± 0.0	0.09 ± 0.0
NH4+ (µg/g)	52.0 ± 1.5	19.0 ± 5.5	30.0 ± 6.0	6.50 ± 1.1	3.40 ± 0.1	5.60 ± 0.6	23.67 ± 7.1	26.0 ± 2.5	18.67 ± 4.2
NO3 + NO2 (µg/g)	79.0 ± 12.4	90.33 ± 4.9	66.67 ± 11.9	0.80 ± 0.0	0.80 ± 0.0	0.80 ± 0.0	97.73 ± 81.3	58.33 ± 15.5	98.0 ± 51.3
Available K (µg/g)	263.33 ± 3.3	286.67 ± 13.3	323.33 ± 12.0	18.0 ± 0.0	27.67 ± 1.8	34.0 ± 7.1	176.67 ± 14.5	203.33 ± 3.3	223.3 ± 3.3
Available P (µg/g)	6.57 ± 0.1	6.57 ± 0.1	6.60 ± 0.1	1.77 ± 0.0	1.93 ± 0.0	1.97 ± 0.1	15.0 ± 0.6	14.67 ± 0.3	14.0 ± 0.0

Note: Values represent mean ± standard deviation (n=3). Significant at the p<0.05 value. OM = Organic Matter; CEC = Cation Exchange Capacity. Control = no biochar additions; Surface = biochar top-dressed on soil column; Mixed = biochar incorporated throughout the soil column.

Discussion

- The effects of biochar amendments on soil chemical properties vary among soil type and by application type, with mixing treatments having the greatest positive effect on soil nutrient status.
- Incorporation of biochar into the soil likely enhances the formation of organo-mineral relationships and alterations of soil chemical properties at a faster rate than top-dressing biochar. This may explain the greater response in mixed treatments on nutrients.
- Increases in K are likely a function of increased CEC
  - It is possible that biochar alters colloid properties to favor adsorption of K relative to other cations, resulting in observed increases in K.
  - Biochar itself could contain exchangeable K, resulting in increases of K following additions of biochar.
- Decreases in ammonium may have resulted from immobilization due to increased C:N ratio after biochar additions, or from losses due to leaching.
- There was no effect on ammonium in the Mollisol, likely because it was a fertilized agricultural soil with a lower C:N ratio and higher available N.
- Biochar additions will result in improved soil chemical properties in both forest and agricultural soil types, but the extent of improvement will vary by soil type and application method.
- Biochar can be used as a soil amelioration tool and can increase the recalcitrant soil carbon pool, resulting in a long-term carbon sequestration.

Summary

- Biochar application method is an important factor in nutrient responses
- Mixed biochar treatments alter exchange sites and increases CEC of all three soils
- Both biochar treatments resulted in significant increases in carbon and organic matter among all soil types
- Potassium significantly increased in both the Andisol and Mollisol with biochar additions, but was unchanged in the Spodosol.
- Ammonium significantly decreased with both biochar treatments in the Andisol only.

Acknowledgements

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