Field and Laboratory Testing of Biochar Amendments for Howard EcoWorks

An evaluation of the properties of various biochar-amended soils constructed by Howard EcoWorks at Howard Community College.

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PROJECT DESCRIPTION

The University of Delaware participated in Howard EcoWorks' Transform Howard demonstration project to assess five biochars - one commercially produced and four kiln-produced - to quantify their ability to retain water, alter stormwater infiltration and thus pollutant removal, and sequester carbon when amended to a representative Howard County soil. A standard suite of laboratory tests was used to quantify biochar particle sizes, chemical composition, surface area, internal pore volume, and particle density. Two kiln-produced biochars from ash and Privet feedstock and a commercial biochar, Rogue, were amended to a representative soil in Howard County in July 2022. Subsequent field and laboratory tests on in-tact soil cores were used to quantify the benefit of biochar amendments and any differences between the performance of the commercial versus kiln-produced biochars. Five field measurement campaigns (09/02/2022, 11/04/2022, 02/24/2023, 09/16/2023, 02/24/2024) were conducted to gather necessary data, which were supplemented with laboratory analyses of field cores for stormwater retention properties.

OBJECTIVE

This project aims to assess the utility of using locally-produced biochars from wood and plant waste rather than more expensive and non-locally produced commercial bicohar for amending a Howard County soil for stormwater treatment. This report will discuss results obtained from field and laboratory testing.

PROJECT AREA

The field site is near the athletic fields at Howard Community College. Site latitude and longitude coordinates are (39.21141, -76.87666). A vegetated filter strip adjacent to a pedestrian path was the site selected for biochar testing. Figure 1 depicts the overall landscape of the field site with the testing site location marked with a blue pin. Figure 2 illustrates a closer look at the field site, including the testing plot locations and dimensions.

Figure 1: Site Location

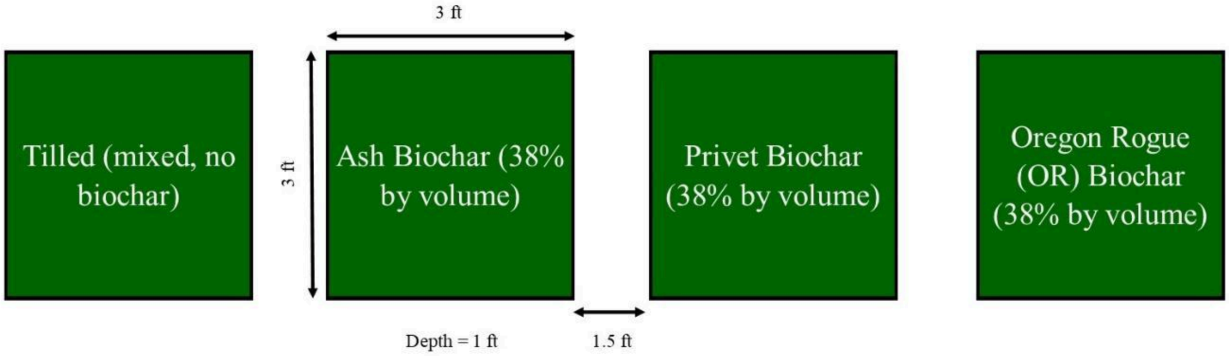


Figure 2: Treatment Area Diagram

BIOCHAR SELECTION AND FIELD CONSTRUCTION

Selection, Production, and Laboratory Testing

Howard EcoWorks (HEW) selected the kiln-produced biochar feedstocks. HEW decided to test waste biomass from collecting several plant species prevalent in Howard County: Autumn Olive, Paulownia, Chinese Privet, and Ash. Autumn Olive, Paulownia, and Chinese Privet are non-native plants regarded as invasive species in many regions of the US, including Howard

County. Ash is a deciduous tree native to Howard County, but its population has been depleted due to the invasive emerald ash borer. Organic waste from each of these plants was collected by HEW and fed into a Ring of Fire kiln (Wilson Biochar, LLC) to be converted into biochar. This process was completed over several days in the Summer of 2022 and followed instructions provided by Kelpie Wilson of Wilson Biochar Associates and her publication, The Biochar Cookbook (2020). In total, 270 L of Ash and 283 L of Privet biochar (uncrushed) were produced for field applications, while smaller amounts of biochar were produced from Autumn Olive and Paulownia feedstocks. Biochar samples were analyzed at the University of Delaware and a commercial laboratory (Control Laboratories, Watsonville, CA) and tested for carbon content, surface area, particle size distribution, and extractable ions. Mercury porosimetry measurements (Particle Testing Authority, Norcross, GA) were also made on all biochars to determine each biochar's internal pore volume, skeletal density, and envelope density. Similar measurements were made on the commercially available biochar tested in this project, Rogue Biochar (Oregon Biochar Solutions, White City, OR).

Field Installation

The field site was prepared on July 27, 2022. Each treatment plot is 0.9 meters wide by 0.9 meters long and 0.9 meters deep (Figure 2). The plots are 0.3 meters from the paved walking trail and 0.46 meters separate each treatment plot. To begin the installation, the plots were de-sodded and excavated. Then, all native soil gathered from the four plots were mixed together. Native soil was returned to the control/tilled plot. The biochar was prepared through a crushing process where they were run over by a truck and tamped until a uniform consistency was achieved. Next, the biochars were mixed with the remaining native soil using shovels at the volumetric proportions shown in Table 1 and added to the appropriate plots. Finally, the plots were topped with grass seed and straw. The grass seed used was a mix of perennial ryegrass and Kentucky bluegrass.

Table 1: Biochar Bulk Volume Proportions at Installation

	Native Soil (Liters)	Biochar (Liters)	Total Volume (Liters)	% by Volume Soil	% by Volume Biochar
Control/Tilled	227	0	227	100%	0%
Ash	123	76	199	62%	38%
Privet	151	95	246	62%	38%
Oregon Rogue	151	95	246	62%	38%

FIELD MEASUREMENTS

Compaction

Soil compaction was measured using a dynamic cone penetrometer (DCP 9 Model K-100 A, Kessler Soils Engineering Products, Inc., Leesburg, Virginia, USA). A sliding hammer weighing 8 kg was used. This hammer was raised to the top set point, released, and then fell by gravity to hammer the DCP tip into the soil. The penetration distance for each blow was measured automatically and recorded in mm/blow, which was then used to compute the stiffness of the soil following standard procedures (ASTM D6951/D6951M, 2018). One to four measurements were made per treatment plot during each field measurement campaign. Soil compaction was reported as the resistance pressure to penetration in kilopascals (kPa).

Infiltration Rate and Saturated Hydraulic Conductivity

The water infiltration rate of each treatment plot was measured using Modified Philip Dunne (MPD) Infiltrometers (Upstream Technologies Inc., New Brighton, Minnesota). Infiltration rates were reported as the speed at which the water level drops 5.0 cm in the instrument and into the soil (cm/h). Four such measurements were made at each treatment plot for each measurement campaign, and the mean of the measurements was reported. The saturated hydraulic Conductivity (K_{sat}) was also computed for each treatment using the raw data obtained from the

MPD Infiltrometers and measurements of the soil volumetric water content before and immediately after completion of the MPD tests.

Volumetric Water Content

The volumetric water content, the volume of water held in soil divided by the total soil volume, was measured over time using an SM150T probe (Delta-T Devices, London) by students at Howard Community College. Measurements were taken approximately once weekly from November 19, 2022, through March 26, 2024: five measurements were made per treatment plot. One measurement was made in the center of the treatment plot, and the four other measurements were taken from the center of each quadrant of the treatment plot. The raw data were converted to volumetric water content, averaged, and plotted over time using a calibration curve developed using data collected through a calibration experiment conducted in the laboratory.

Before and after each MPD infiltration test, volumetric water contents were also measured in the soils impacted by water infiltration with a Fieldscout TDR 150 (Spectrum Technologies, Inc., Aurora, IL). Volumetric water contents are required to convert raw MPD infiltration data to saturated hydraulic Conductivity. The raw data were converted to volumetric water content using a calibration curve developed using data collected through a calibration experiment conducted in the laboratory.

Vegetation Analysis

Photographs of the vegetation growing at the treatment sites were taken during each \site visit using an Apple iPhone 13 Pro Max. Images were then quantitatively assessed using standard approaches developed by turf grass scientists. The software program Turf Analyzer (Green Research Services, LLC) was used to analyze the percent coverage of green turfgrass in the images taken of the treatment sites.

LABORATORY MEASUREMENTS

Field Capacity and Wilting Point

The water retention properties of in-tact sample cores collected from the biochar-amended and adjacent control soil were measured using a Pressure Plate Extractor. Two soil cores were taken from each treatment site at the end of the testing period, saturated with water in the lab, and then placed in the pressure plate apparatus under 1 bar of pressure. Each core had a volume of 251 cm^3 and was collected from the top layer of soil in each treatment plot. After the system reached equilibrium, field capacity was determined. Soil cores were then placed in the pressure plate apparatus under 15 bars of pressure. After the system reached equilibrium, wilting point was determined.

TDR and SM Probe Calibrations

For this procedure, 2.5 quart plastic buckets (18 cm in diameter and 17.5 cm tall) with screen-covered holes on the bottom to allow evaporation were packed with soil and biochar mixtures to replicate field characteristics. Samples of the field soil without biochar, i.e., the control soil, were also tested. The buckets of soil were completely saturated with water, and soil moisture readings were taken along with the bucket's weight. The buckets were then placed in a hot room at 35 C and allowed to dry slowly by evaporation. Weights of the buckets and soil moisture readings were taken approximately every 24 h. Soil moisture was measured using the Fieldscout TDR 150 Soil Moisture Meter and an SM150T soil moisture sensor every 24 h.

This calibration procedure aims to evaluate the relationship between TDR/SM readings and the volumetric water content of the soil. Once the relationship can be described with calibration equations, which may differ for each biochar/soil combination, TDR and SM measurements made in the field can quickly be converted to volumetric water contents. A more detailed explanation of the procedure is provided in Appendix A, along with sample plots showing the relationship between a soil's volumetric water content and instrument readings.

RESULTS AND DISCUSSION

Soil and Biochar Characterization

Table 2 summarizes important characteristics of the native soil and biochars used in the field trials. The kiln-produced biochars were analyzed by Control Laboratories (Watsonville, CA) in July 2022. Information on the Oregon Rogue biochar was obtained from a previous test performed in February 2017, also by Control Laboratories. Some notable observations are that the Rogue biochar has a significantly lower dry bulk density than the locally-produced biochars. Rogue biochar also shows a higher surface area, which allows for more microbial activity and greater water retention in the soil, thus improving soil structure. Thus, while the bulk volumes of each biochar in the treatment plots were identical, the mass fractions of biochar are significantly different.

The particle size distribution of the native soil is shown in Figure 3. This distribution determined that the soil is 7% clay, 30% silt, and 63% sand, classifying it as a sandy loam according to the United States Department of Agriculture (USDA) Soil Textural Triangle.

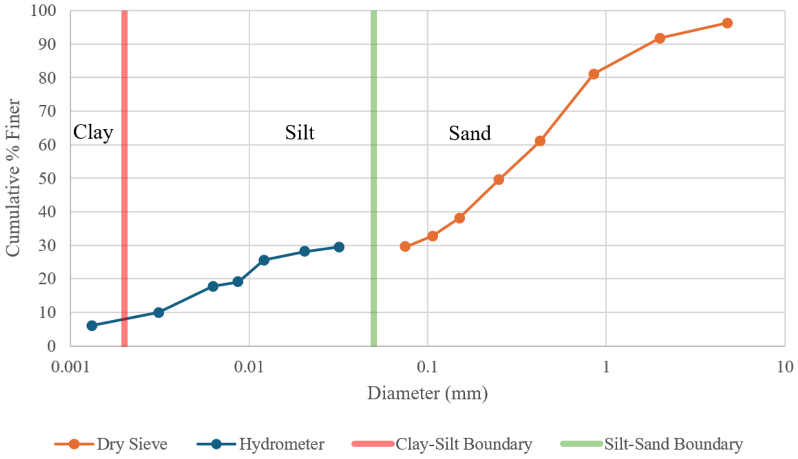


Figure 3: Native Soil Particle Size Distribution

Table 2: Physiochemical properties of the field soil, Rogue Biochar, and the four biochars produced for this project.

Parameter		**Field Soil**	**Rogue Biochar**	**Privet Biochar**	**Ash Biochar**	**Autumn Olive Biochar**	**Paulownia Biochar**
Particle size (% mass)	Fine gravel (6-2 mm)	8.2	33.3 (1.3)	56.7 (2.3)	46.9 (1.2)	46.1 (1.9)	30.2 (0.3)
	Sand (2.0 -0.06 mm)	65.6	66.7 (1.2)	18.6 (2.8)	22.7 (0.7)	22.3 (2.7)	21.4 (0.3)
	Silt (0.06-0.002 mm)	16.3	-	13.2 (0.5)	16.8 (0.4)	18.3 (0.5)	23.5 (0.3)
	Clay (<0.002 mm)	9.9	-	11.5 (0.5)	13.6 (2.8)	13.3 (0.6)	24.9 (0.4)
Texture		Sandy Loam	n/a	n/a	n/a	n/a	n/a
Particle density (g/cm^3)	Skeletal	-	0.98	3.1	3.4	4.2	4.8
	Envelope	-	0.44	2.1	2.6	3.2	1.8
Bulk density (kg/m^3)		1209	7.85	274	232	240	183
BET surface area (m^2/g)		-	553 (8)	259	295	226	252
Organic matter (% mass)		1.83 (0.03)	88.8 (0.4)	74.0	73.9	55.1	52.6
pH		7.5	10.5	9.7	9.4	9.6	9.7
Cation exchange capacity (meq/100g)		7.2 (0.2)	54.6 (0.6)	-	-	-	-
Exchangeable cations (meq/100g)	Ca	11.2 (0.2)	35.3 (0.1)	-	-	-	-
	K	0.25 (0.01)	22.3 (0.1)	-	-	-	-
	Mg	0.33 (0.01)	7.28 (0.01)	-	-	-	-
	Na	0.22 (0.16)	11.18 (0.05)	-	-	-	-
Extractable nutrient (mg/kg)	P	15.53 (0.07)	41.3 (0.5)				
	K	80.3 (.4)	1024 (14)				
	Ca	1790 (20)	749 (6)				
	Mg	43.0 (0.5)	128.2 (1.9)				
	Mn	58.4 (0.7)	29.9 (0.3)				
	Fe	70.0 (1.1)	49.0 (0.7)				
	S	13.21 (0.02)	32.7 (0.9)				
	Na	5.63 (0.02)	280 (4)				
	Al	297 (3)	53.6 (1.5)				

The particle size distributions of each kiln-produced biochar and Rogue biochar using sieves alone are shown in Figure 4a. While Rogue biochar has a uniform particle size and is sand-size, the kiln-produced biochars are well graded with a substantial amount of gravel-size particles > 10 mm and small silt and clay-sized particles. Because of the dramatic differences in particle size, the effect of biochar amendment on pore size, pore structure, water retention, and water infiltration when mixed with soil are expected to be very different. Figure 4b depicts a more completed particle size distribution of of the kiln-produced biochars via wet and dry sieve analysis (ATSM-422) and hydrometer analysis (ATSM-D8928).

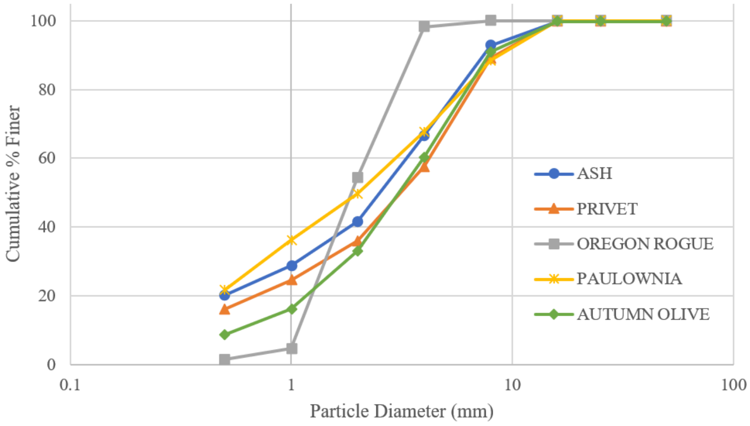


Figure 4a: Biochar Particle Size Distribution

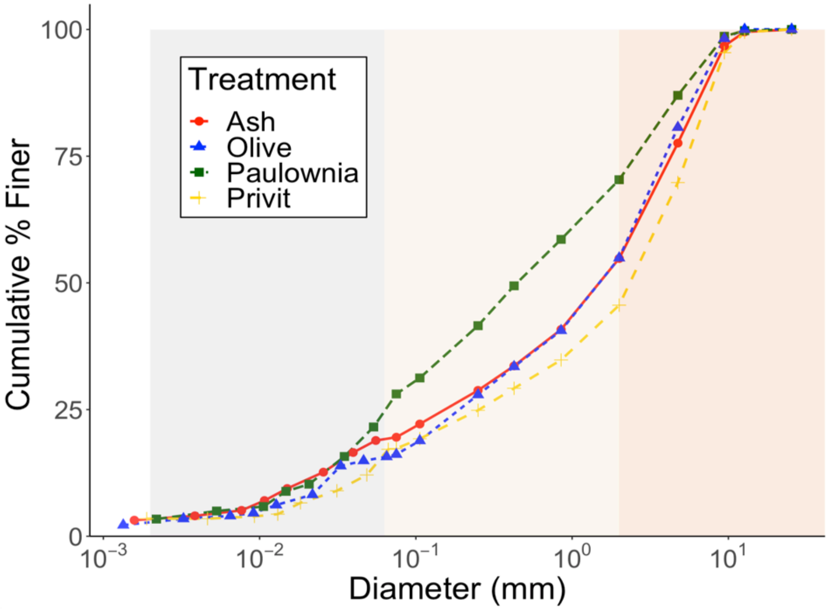


Figure 4b: Hydrometer and Sieve Analysis - shaded regions correspond to soil particle size: white = clay, gray = silt, tan = sand and brown = gravel

Compaction – Penetration Resistance Pressure

Compaction was assessed using the penetration resistance pressure reported in kilopascals (KPa). Data are shown for undisturbed soil (UNDISTURBED), with no tillage; soil that was tilled but no biochar added (TILLED), and soils that were amended with Ash (ASH), privet (PRIVET), and Rogue (OREGON ROGUE) biochars.

Mean compaction data are plotted with +/- one estimated standard error of the mean in Figure 5. Each data point represents an average of four measurements taken at a 0-30 cm depth below the surface. From Figure 5, it can be concluded that overall, compaction increased with time in all treatment sites besides the undisturbed soil, which is to be expected because of natural settlement. Approximately one year after installation, little further change was observed in compaction in the treatment plots. In addition, the soil amended with Rogue biochar showed the lowest penetration resistance pressure of all biochar treatments, which is likely because this was the biochar with the smallest envelope and skeletal density (Table 1).

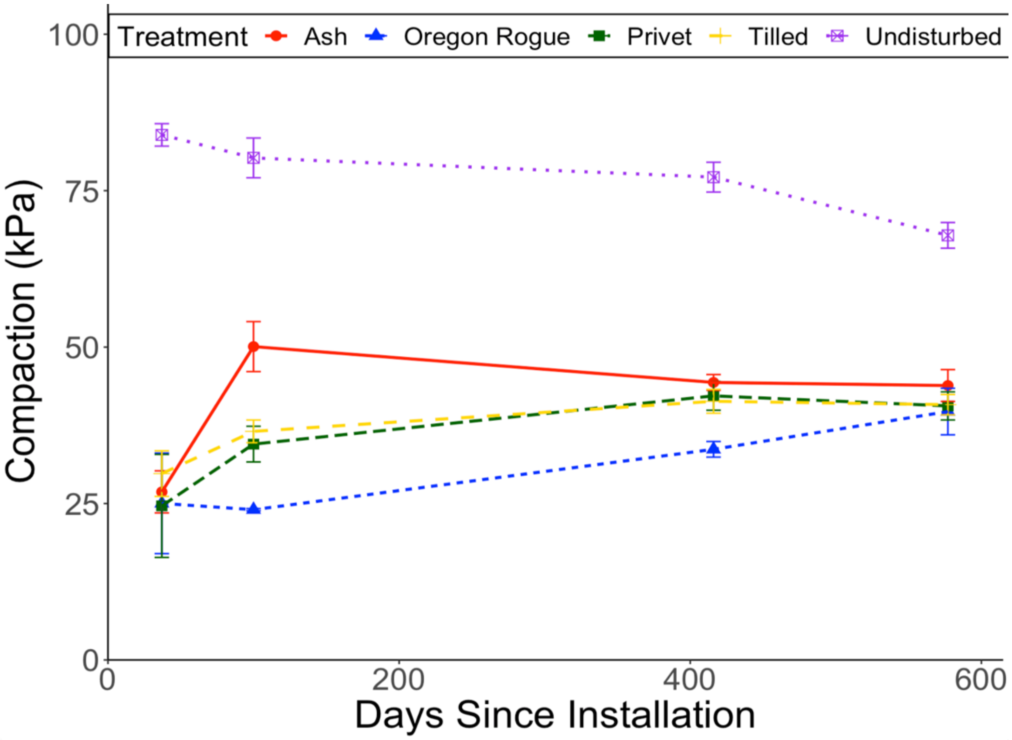


Figure 5: Mean Compaction

Saturated Hydraulic Conductivity

Figure 6 shows each treatment site's mean saturated hydraulic Conductivity (K_{sat}), plotted with +/- one standard error of the mean as a function of measurement time. Saturated hydraulic Conductivity is the speed at which water passes through saturated soil pores when subject to a unit hydraulic gradient. While soil compaction increased with time after amendment for all treatments, except for undisturbed soil (Figure 5), the saturated hydraulic Conductivity showed no similar trend. Instead, K_{sat} varied with season. The first measurement of K_{sat} at ~ 60 days was very high for all treatments since the soils were still very uncompacted (Figure 6). The smallest K_{sat} was in the winter months (blue shaded area), at ~ 220 and ~570 days after installation, and the highest K_{sat} occurred in the late summer (white area), ~ 100 and 420 days. At all measurement times, the smallest K_{sat} was for undisturbed soil, while all biochar amendments resulted in greater infiltration. The ability of the biochar amendments to increase K_{sat} by > factor of 3 at most measurement times indicates that biochar amendment would result in significant stormwater infiltration, thus reducing stormwater runoff to nearby water bodies. The figure shows that the Rogue biochar-amended soil consistently exhibited a higher K_{sat} than the other biochar-amended soils. However, the Privet biochar amended soil had similar Ksat measurements to Rogue biochar for the final two testing dates.

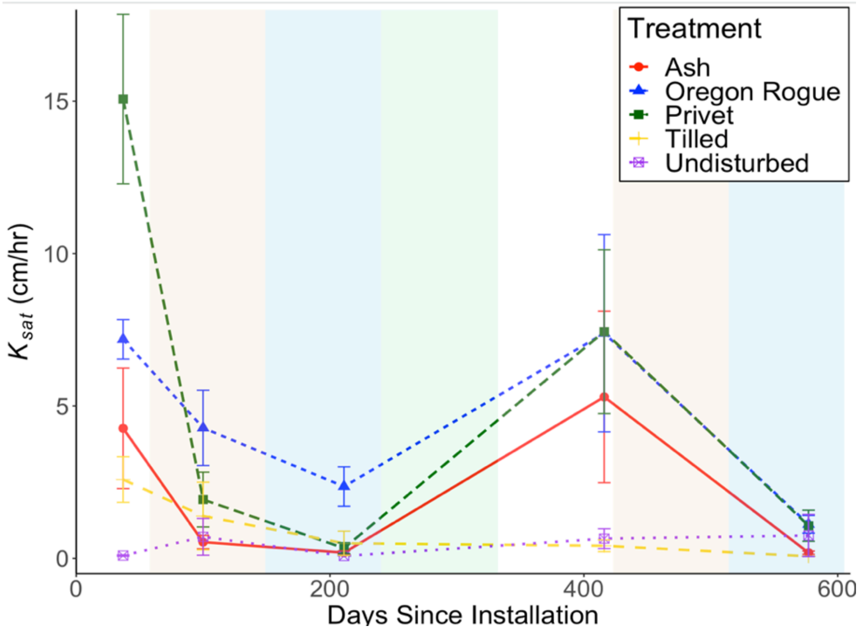


Figure 6: Mean K_{sat} – shaded regions correspond to season: white = summer, tan = autumn, blue = winter and green = spring

Infiltration Rate

In Figure 7, the average infiltration rate of each treatment site is shown for all testing dates, plotted with +/- one standard error of the mean. The infiltration rate differs from K_{sat} in that it is the rate at which water infiltrates the ground, which depends on the local volumetric water content at the measurement time. The K_{sat} is a soil property independent of the soil volumetric water content. The soil performs better for stormwater treatment if the infiltration rate is high. As the treatment plots aged, the average infiltration rate became more uniform between the different treatments, which is likely due to soil compaction. Measurements on 9/2022 were high for all treatments, including the tilled soil with no biochar, since the soils had been recently tilled and amended, and natural compaction was minimal. Differences in infiltration rate on subsequent dates are attriubed to seasonal effects on plant growth and soil microbes, which altered pore structure and infiltration. Comparing the last two testing dates, all three biochar plots show similar results for each date. Although there is significant variability, which is to be expected, the Privet biochar performed similarly to Rogue biochar, and both were better than the Ash biochar.

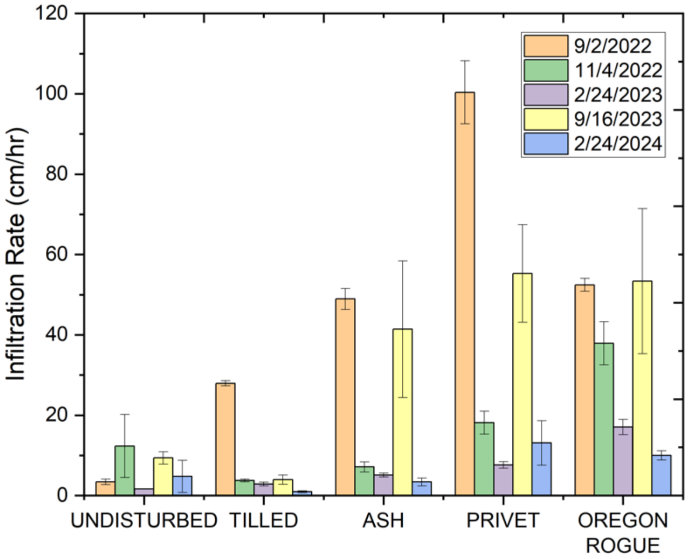


Figure 7: Mean Infiltration Rate

Volumetric Water Content Over Time

Figure 8 shows the volumetric water content of the four treatment plots over time. Raw data collected by the SM150T meter was converted to volumetric water content (VWC) using the calibration equation for each soil/biochar combination. Each data point represents an average of data taken at each treatment plot over a season: fall, winter, or spring. Each point is plotted with +/- one standard error of the mean. The data is presented this way to show how the different biochars perform with regard to the weather conditions over time.

From Figure 8, it can be concluded that all three biochar amendments increased the volumetric water content of the native soil over time: the tilled soil without biochar consistently had the smallest volumetric water content. The graph also shows that the Ash amended soil exhibited a higher VWC than the Privet and Oregon Rogue throughout all seasons (white = summer, tan = fall, blue = winter and green = spring).

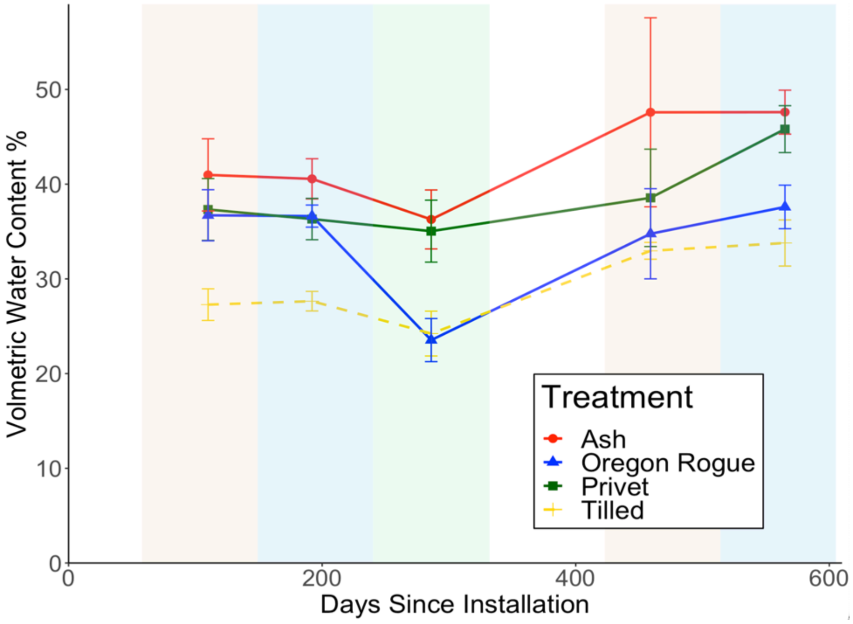


Figure 8: Mean Volumetric Water Content (VWC) by Season – shaded regions correspond to season: white = summer, tan = autumn, blue = winter and green = spring

Vegetation

Pictured below in Figures 9 and 10 are images showing the vegetation at each treatment plot for the September 2, 2022, and November 4, 2022, testing dates. In September 2022, the grass seedlings were growing but did not fill the photographs since seeding occurred at the end of July

2022. From the pictures, it is evident that there was significant vegetation growth between September 2 and November 4. In September, all treatment sites showed similar amounts of vegetation; however, more straw had been removed from the OR (Rogue biochar) plot than the others. In November, the tilled and OR (Rogue biochar) plots showed slightly more vegetation than the Ash and Privet plots. There were no noticeable differences in vegetation cover between the treatments during the remaining testing dates. This can be seen in Figure 11, where the mean percent vegetation coverage is plotted for each testing date.

Figure 9: Vegetation in September 2022

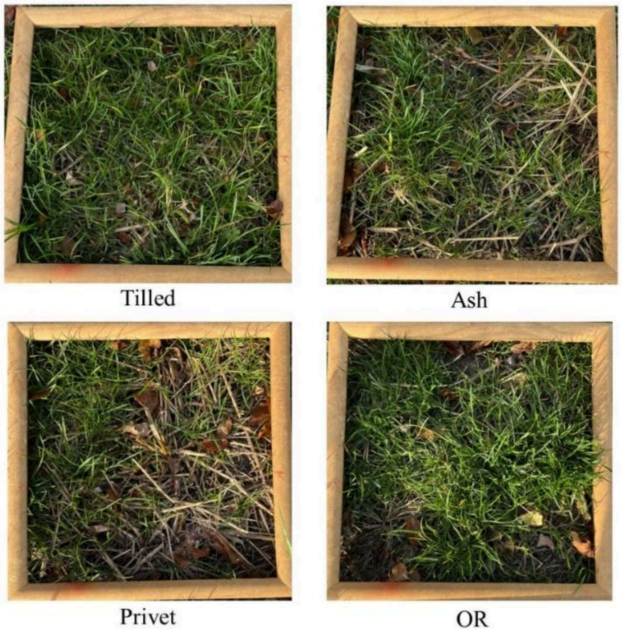


Figure 10: Vegetation in November 2022

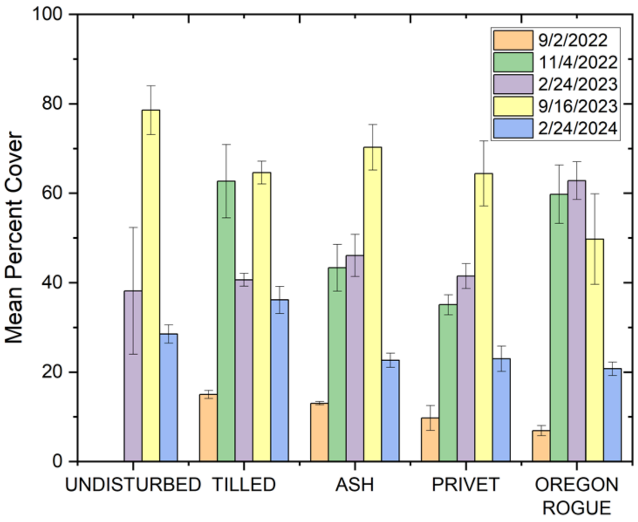


Figure 11: Mean Percent Vegetation Cover

Field Capacity, Wilting Point, and Plant Available Water

Figure 12 shows the field capacity, wilting point, and plant available water (PAW) for each treatment site determined from soil samples collected in November 2022. The field capacity for each treatment site was determined from in-tact cores. It is important to note that all three biochar-amended soils showed a higher field capacity than the tilled (control) soil. Field capacity represents the amount of water a soil can hold after gravity has drained excess water. With a larger field capacity, the soil can hold more water after a storm event. The average wilting point for each treatment site was also determined from the intact cores. The wilting point represents the amount of water a soil can hold but is not available to plants. The soil retains some water at this point, but it is too difficult for plant roots to extract it, as it is being held at such a high pressure.

With these field capacity and wilting point measurements, plant available water (PAW) can be determined: PAW is the difference between field capacity and wilting point. More plant available water allows better vegetation performance, thus enhancing soil structure and likely stormwater infiltration. As shown in Figure 13, all three biochar-amended soils have much larger PAWs than the Undisturbed (UND) and Tilled soil, though there is little difference between the three treatments.

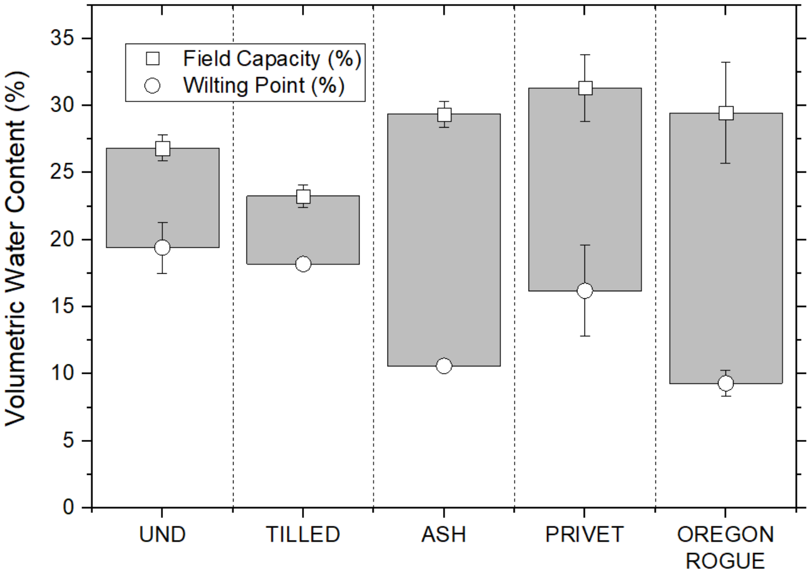


Figure 12: Plant Available Water

Water Retention

The stormwater that may be retained for each treatment site is shown in Figure 13. This water is defined as the volume of water a soil holds after a storm saturates the soil minus the initial volumetric water content before the storm starts. The initial volumetric water contents below were taken before the MPD Infiltrometer tests, and the final volumetric water contents were taken immediately after the MPD tests were completed. The difference between these two measurements indicates the soil's approximate stormwater water holding capacity or water retention.

Figure 13 shows that the total water retained within the biochar-amended soils was similar to the undisturbed and tilled soils. The biochar-amended soils had higher initial and final water contents, but the water retention, the difference between the initial and final water contents, was similar to that for the undisturbed and tilled soils. However, the amended soils showed a higher initial water content, indicating these soils retain water over a more extended time. There is little difference between the three biochar-amended soils.

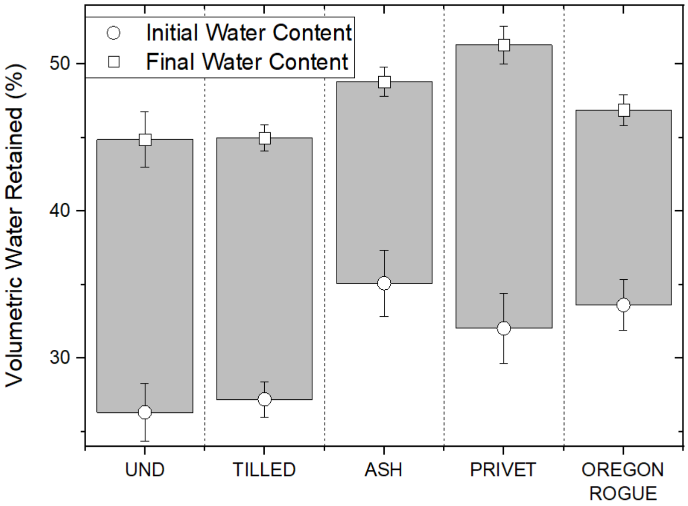


Figure 13: Water Retention

Response Factors for All Parameters

The response factor represents the ratio of the treatment response to the control response (e.g., $K_{sat\text{-}biochar}/K_{sat\text{-}tilled}$). Response factors allow different parameters to be compared to each other since it is a dimensionless value.

Figure 14 depicts the compaction and saturated hydraulic Conductivity response factors (K_{sat}) and is plotted on a $\log_{10}$ scale. Therefore, factors less than zero represent a decrease from the control value (tilled soil without biochar), and factors greater than zero represent an increase from the control value. Here, reducing the compaction response factor and increasing the K_{sat} response factor is desirable. Therefore, it can be concluded that Rogue biochar amended soil exhibited the most significant response: increasing K_{sat} and decreasing compaction compared to the tilled soil at all measurement times. Ash biochar amended soil exhibited the least significant response for both compaction and K_{sat} of the three biochar treatments.

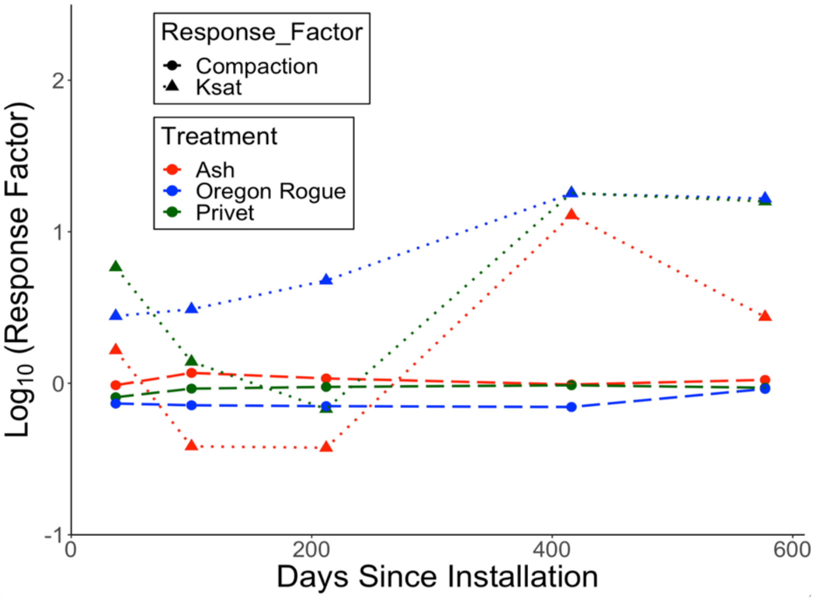


Figure 14: Compaction and Saturated Hydraulic Conductivity Response Factors

Figure 15 shows the response factor for the volumetric water content by season (not plotted on a $\log_{10}$ scale). Here, factors less than one represent a decrease from the control value (tilled soil without biochar), and factors more significant than one represent an increase from the control value. It can be concluded that the Ash biochar amended soil exhibited the most significant response, and the Rogue biochar exhibited the least significant response.

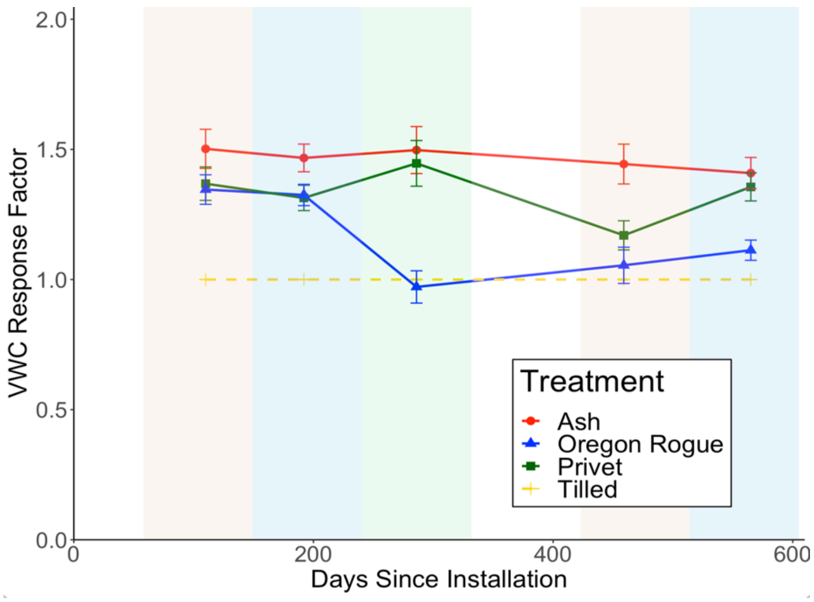


Figure 15: Volumetric Water Content Response Factor – shaded regions correspond to season: white = summer, tan = autumn, blue = winter and green = spring

CONCLUSIONS AND RECOMMENDATIONS

This project examined the performance of kiln-produced biochars to a commercially produced biochar on hydrologic properties of compacted urban soil. The observed effects from the field and laboratory data varied with the different biochars and with time. It can be reasonably concluded that of the tested kiln-produced biochars, the soil amended with Privet biochar exhibited a higher K_{sat}, lower compaction, and higher VWC over time. However, the soil amended with the commercial Rogue biochar consistently exhibited lower compaction and frequently a higher K_{sat}. These responses are easily seen and summarized in Figures 13 and 15. All biochar amended plots responded to the treatment, with the Privet biochar performing the best of the kiln-produced biochars and Oregon Rogue performing the best overall.

Based on the results from this study, the Privet biochar produced locally using a kiln is a good candidate for soil amendment to improve the hydrologic function of soils in Howard County, MD. While the improvement in K_{sat} is not as significant as Rogue biochar, soil amended with Privet biochar retains water better than Rogue biochar. Thus, large-scale application of Privet biochar to urban soils in Howard County may be beneficial. However, future work should examine the utility of Privet biochar in soils also found in Howard County but different from the soil tested in this study.

APPENDIX A: CALIBRATION CURVE PROCEDURE AND DATA

Full Procedure for TDR 150 and SM 150T calibration:

a. Obtain 8 2.5-qt buckets and drill 6 holes in the bottom. Cover the bottom with mesh to allow water to drain, but soil to be kept inside the bucket.
b. Using the volume of the buckets and the percent by volume of biochar and soil used in the field (provided by Lori Lilly) calculate roughly how much soil and biochar should be used.
c. Measure out (by volume) the biochar and soil into aluminum pans and place in the oven at 105 C for 24 hours.
d. Remove pans from the oven, weigh pans, and record.
e. Measure the volume of the soil-filled region of the buckets using water displacement.
f. Weigh each empty container to know the starting mass.

For Control buckets:

g. Assume a dry bulk density of the native soil is 1.3 g/cm^3.
h. Determine the mass of dry soil needed per bucket using the volume of the container (from step 4) and desired dry bulk density (from step 6).
i. Measure out the dry mass of soil needed, increasing by 25% so that there is extra.
j. Pack the container by gentle rodding:
    a. Add 1-cm thick layer of dry soil to container.
    b. Moisten soil using DI water
    c. Using a ring stand rod, rod the soil to a reasonable packing. Count the number of plunges.
    d. Repeat steps a-c. Use the same number of plunges (around 40).
    e. Pack to the lower lip of the container, where the volume of the container was measured using water displacement.

k. Weigh the fully packed container and record.

l. Weigh the remaining amount of dry soil that was not used in packing.

m. Subtract this amount from the total amount of dry soil weighed out to determine the amount of dry soil used in the container.

n. Repeat steps 6-12 for another replication.

For Soil & Biochar mixed buckets:

o. Assume a dry bulk density of soil + 4% biochar in the container = 1.09 g/cm^3. This assumes a dry bulk density of native soil of 1.3 g/cm^3 and that each 1% mass fraction of biochar reduces the soil bulk density by 4%.

p. Determine the total mass of dry soil and biochar needed per bucket using the volume of the container (from step 4) and desired dry bulk density (from step 13).

q. Given the biochar is 4% of the total mass in the container, calculate the dry mass of biochar needed.

r. Given the soil is 96% of the total mass in the container, calculate the dry mass of soil needed.

s. Measure out the dry masses of soil and biochar into separate buckets.

t. In a large mixing bowl, mix the soil and biochar:

    a. Add about 1/4 of the soil and 1/4 of biochar to the mixing bowl.

    b. Add some DI water and mix to a uniform consistency.

    c. Repeat steps a-c until all biochar and soil is mixed in the bowl uniformly.

u. Pack the container according to step 9 and 10 above (using the moist soil and biochar mixture, not dry soil).

v. Place the remaining soil and biochar mixture into an aluminum pan and let dry in the oven for 24 hours at 105 C.

w. Weigh the remaining mixture and determine the total dry mass of biochar and soil in the containers.

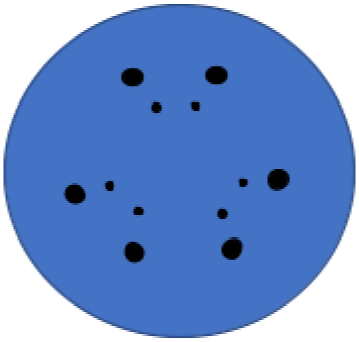
x. Determine the actual dry bulk density of the soil/soil + biochar in the containers.

y. Place buckets in a large tote and propped up on PVC rings to allow water to enter through the holes in the bottom.

z. Fill the totes with water and check periodically throughout the next 48 hours. Continue adding water until the water level is above the soil level in the buckets to ensure full saturation.

After complete saturation:

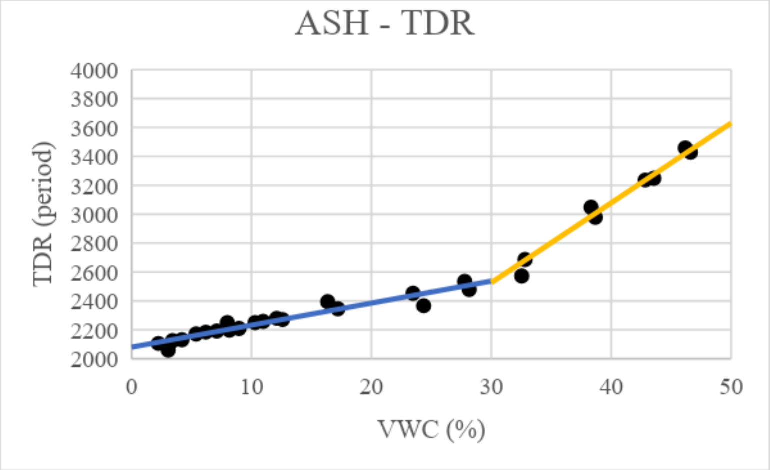
1. There should be water pooled on top of the soil to indicate complete saturation. If there is more than ½ inch of standing water above the soil, gently pour the water off the top of the bucket.
2. Remove the buckets from the tote and let drain from the bottom.
3. Carefully weigh the buckets while sitting in an aluminum pan (tare after placing aluminum pan on scale, then place bucket in pan).
4. Keeping the bucket in the pan, record the following data:
   a. TDR in period mode
   b. Electrical Conductivity in mS/cm
   c. Temperature in Fahrenheit
   d. SM150T reading in mV
5. Take 3 measurements for each of the four data categories. Take from the center of the soil in a triangle like shown:

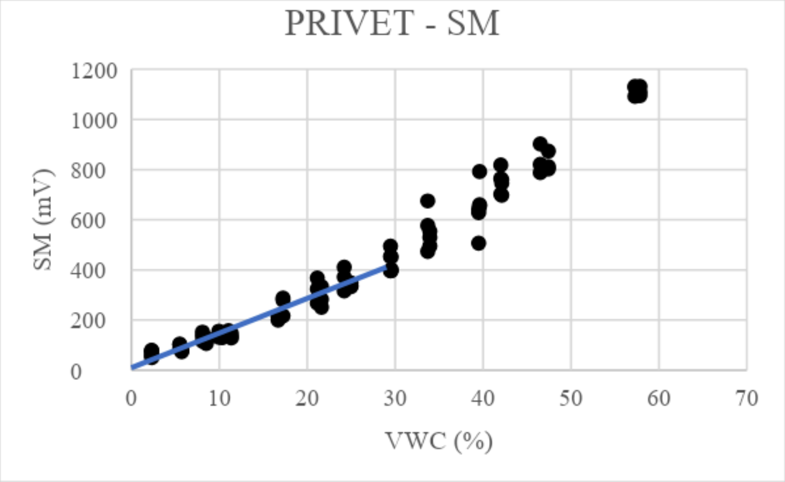


Larger holes indicate TDR150 probe; smaller holes are from the SM150T probe.

6. Take readings every ~12 hours for the first two days. Then take readings every ~24 hours until the soil reaches approximately a volumetric water content of 0.
    a. Try to take readings from the same holes each time. Placement of the probes may need to be adjusted from the diagram shown above due to rocks/other obstructions.

Example Plots:





APPENDIX B: PARTICLE SIZE DISTRIBUTION PROCEDURE

<u>General Hydrometer Procedure using ATSM D7928:</u>

Sample Prep:

1. Obtained biochar sample and sieved over the #10 sieve. Added between 50g and 100g of biochar that passes the #10 sieve and put into a 500 mL Erlenmeyer flask. Then placed biochar that did not pass through the #10 sieve in ziplock bag for storage.

2. Added 250mL of deionizing water to the 50g-100g of biochar sample that passes through the #10 sieve in the last step.
    a. Mixed solution by stirring rod until the biochar looked like it mixed in with the DI water made so the entire biochar sample is exposed to the solution
    b. Covered the top and let the mixed solution sit for 16 hours minimum to allow for temperature stabilization.

3. After sitting for 16 hours minimum, took the sample, poured it into a 1000mL glass cylinder
    a. Used a squirt bottle w/ room temp DI water to get all of solution out of the flask

4. Filled cylinder up to the 1000mL mark with DI water after the slurry in completely poured in
    a. Poured in ~150mL of DI water into cylinder before adding the slurry so the slurry won'tt stick to the bottom

4. Rotated cylinder 180 degrees (vertically) for 1 minute with a rubber stopper

5. Put the 152H hydrometer in right away after done rotating the cylinder and recorded the hydrometer readings at times: .25, .5, 1, 2, 5, 15, 30, 60, 240, and 1440 minutes
    a. Left the 152H hydrometer in the cylinder for the first 2 minutes of readings
    b. Placed the hydrometer in at least 15 seconds before the scheduled reading so it can stabilize in the solution

6. Recorded temperature for each reading and the top of the meniscus on the hydrometer

Dry Sieve Analysis using the ASTM-422

1. Obtained 250-300g of oven-dried sample and washed it over the #200 sieve with deionizing water until the water ran clear, then dried it again for 24 hours minimum at 110 °C.
2. Selected clean and dry sieves to be used and weighed them out:
   a. Used sieve #'s: 1", ½", $\frac{3}{8}$", 4, 10, 20, 40, 60, 140, and 200.
3. Sieved for 12 minutes and recorded the mass of the sieves with the soil retained on them (subtract the clean weight of the sieve and the sieve + soil to get the weight of the soil retained)
4. Stored dried material in ziplock bag