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.

Leslie Webb

Paul T. Imhoff

Department of Civil and Environmental Engineering

University of Delaware

February 6, 2023

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 bicohar particle sizes, chemical composition, surface area, internal pore volume, and particle density. Two of the kiln-produced biochars (ash and privet feedstock) and a commercial biochar (Oregon 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 short-term benefit of biochar amendments and any differences between the performance of the commercial versus kiln-produced biochars.

OBJECTIVE

The objective of this project is to assess and compare the properties of a soil amended with three different types of biochar at Howard Community College. This report will discuss results obtained from field and laboratory testing to date.

PROJECT AREA

The location of 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 path was the sited selected for bicohar testing. Figure 1 depicts the overall landscape of the surrounding area of the field site with the testing site location marked with a blue pin. Figure 2 below depicts a closer look at the field site including the location, dimensions, and labels of the testing areas.

Figure 1: Site Location

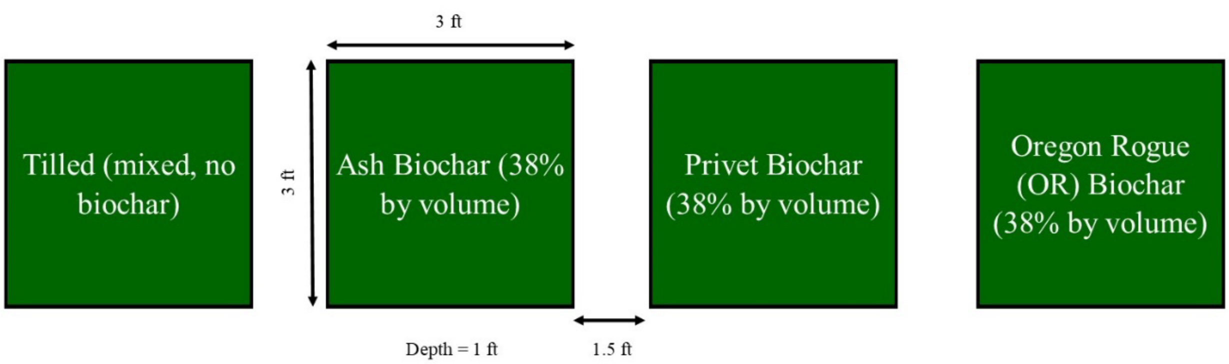


Figure 2: Treatment Area Diagram

FIELD METHODS

Compaction Measurements

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 and recorded in mm/blow, which was then used to compute the stiffness of the soil following ASTM D6951/D6951M (2018). During each field measurement campaign, one to four measurements were made per treatment site. Soil compaction was determined as the resistance pressure to penetration and is reported in kilopascals (kPa). Average pressures are reported for depths of 0-15 cm, 15-30 cm, and 30-50 cm.

Infiltration Rate Measurements

The infiltration rate of each treatment was measured using Modified Philip Dunne (MPD) Infiltrometers (Upstream Technologies Inc., New Brighton, Minnesota). Infiltration rates were reported as the time necessary for the water level to drop 5.0 cm. Four such measurements were made at each treatment site for each measurement campaign, and the mean of the measurements are reported below. Future analyses of the raw MPD data will be used to determine the saturated hydraulic conductivity.

Volumetric Water Content Measurements

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 by students at Howard Community College. Measurements were taken approximately once per week from November 19, 2022 to January 28, 2023. Five measurements were made per treatment site. The raw data were converted to volumetric water content, averaged, and plotted over time using a calibration curve developed using preliminary data. The accuracy of this calibration curve should be checked in the future and volumetric water content will be updated.

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.). 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 the manufacturer's calibration curve. The accuracy of this calibration curve should be checked in the future, particularly for biochar-amended soil.

Vegetation Analysis

Photographs of the vegetation growing at the treatment sites were taken during each field site visit using an Apple iPhone 13 Pro Max. Qualitative observations in the vegetation will be discussed. Images may be quantitatively assessed in the future using standard approaches developed by turf grass scientists.

LABORATORY METHODS

Field Capacity and Wilting Point Analysis

The respective field capacities 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, then placed in the pressure plate apparatus under 1 bar of pressure. After the system reached equilibrium, field capacity was determined. The process for determining wilting point of the amended soils and control soil is ongoing.

TDR and SM Probe Calibration

For this procedure, 2.5 quart plastic buckets, which 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 weight of the bucket. 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 hours. Soil moisture was measured using the Fieldscout TDR 150 Soil Moisture Meter and an SM150T soil moisture sensor.

The purpose of this calibration procedure is to evaluate the relationship between TDR/SM readings and 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. More accurate calibration curves, using adjusted biochar mass fractions and bulk densities, are in the process of being completed.

RESULTS AND DISCUSSION

Biochar Characterization

Tables 1 and 2 summarize important characteristics about the biochars used in the field trials. Some notable conclusions are that the Oregon Rogue biochar has a significantly lower dry bulk density than the Ash or Privet biochars. Oregon Rogue also shows a higher surface area, which allows for more microbial activity in the soil, thus improving soil structure.

Table 1: Dry Bulk Density

Dry Bulk Density (lb/ft^3)	
Ash	14.5
Privet	17.1
Oregon Rogue	4.9

Table 2: Surface Area

Surface Area (m^2/g dry)	
Ash	295
Privet	259
Oregon Rogue	456

Compaction – Penetration Resistance Pressure

Table 3 shows average compaction at increasing depths for each treatment plot. Compaction is described using penetration resistance pressure and values are reported in kilopascals (KPa). During the September 2022 site visit, the soil was still loose and thus data at shallower depths could not be collected at each test location. Values denoted with a "1" are averages of two data points. Values denoted with a "2" represent a single data point. Data are shown for undisturbed soil (UND), with no tillage; soil that was tilled but no biochar added (TILLED), and soils that were amended with ash (ASH), privet (PRIVET), and Oregon Rogue (OR) biochars. Compaction pressures increase with depth, and compaction is smaller for the ASH treatment. Although biochar amendment was intended for 0-30cm depth, the process of mixing the soil and biochar loosened soil up to 50 cm depth, since compaction readings were at least 50% smaller in TILLED than UND for the 30-50 cm depth range. It is also apparent that compaction is increasing with time as the soils “settle:” compaction readings at the same depths are almost all higher in November than September 2022.

Table 3: Compaction Data

	2-Sep Compaction (KPa)		
	0-15 cm	15-30cm	30-50cm
UND.	77.2	88.1	92.4
TILLED	26.0[1]	29.2	46.9
ASH	22.2[2]	27.4	42.8
PRIVET	32.9[2]	24.2[1]	31.5
OR	33.1[2]	22.2[1]	28.5
	4-Nov Compaction (KPa)		
	0-15cm	15-30cm	30-50cm
UND.	63.6	85.6	101.6
TILLED	31.2	36.5	56.7
ASH	42.5	46.1	63.4
PRIVET	28.2	33.6	49.9
OR	24.0	24.4	38.0

Figures 3-5 compare compaction data at descending depths of each treatment site in September and November 2022, where tilled soil = control soil. Mean compaction data are plotted with +/- one estimated standard error of the mean. From these figures, it can be concluded that overall, compaction increased with time in all treatment sites and at all depths. In addition, the soil amended with the Oregon Rogue biochar showed the lowest penetration resistance pressure of all biochar treatments.

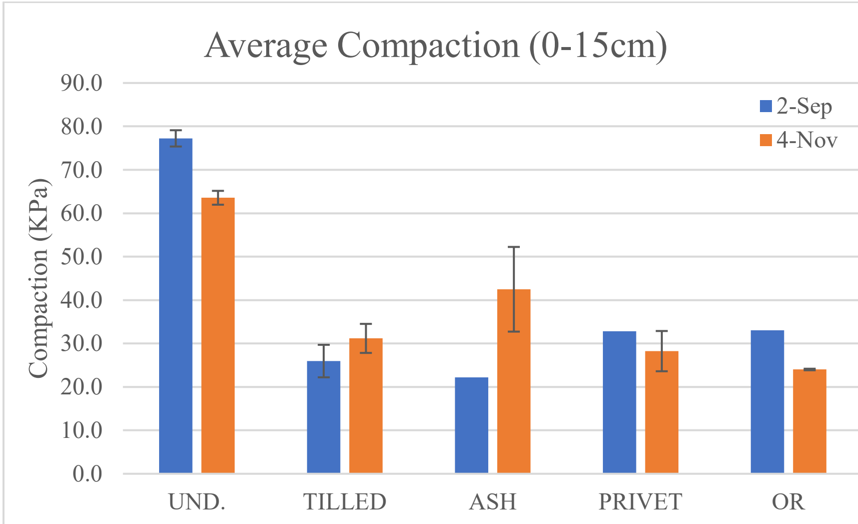


Figure 3: Average Compaction (0-15cm) Over Time

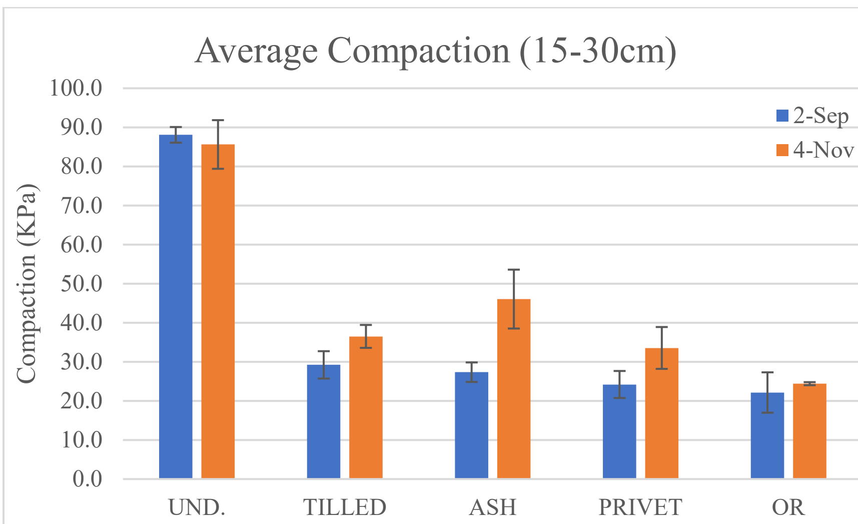


Figure 4: Average Compaction (15-30cm) Over Time

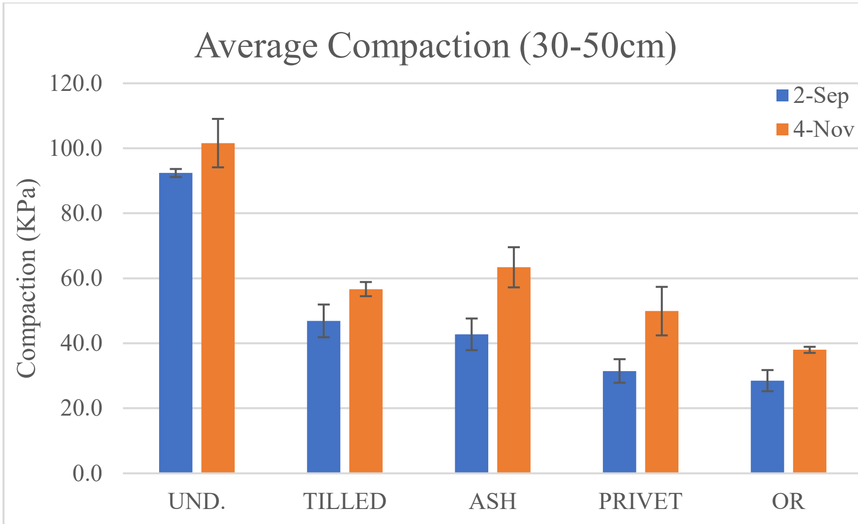


Figure 5: Average Compaction (30-50cm) Over Time

Infiltration Rate

In Figure 6 the average infiltration rate of each treatment site is shown for September and November, 2022. The soil performs better for stormwater treatment if the infiltration rate is high. It can be concluded that the average infiltration rate decreased dramatically with time in the Tilled, Ash, and Privet sites, however not as dramatically in the Oregon Rogue site. More monitoring is needed to evaluate how the different biochars perform with the changing seasons.

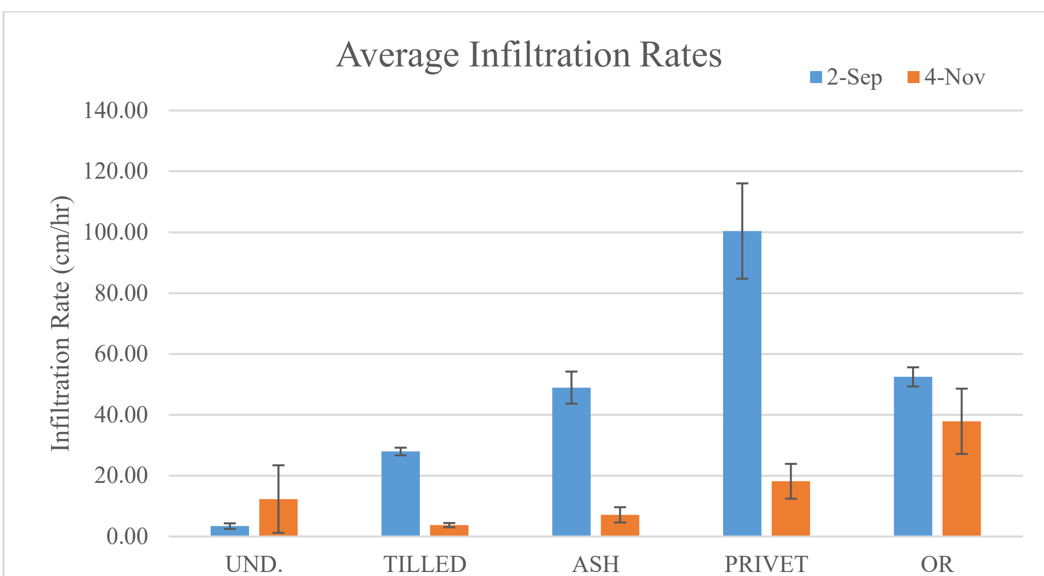


Figure 6: Average Infiltration Rates

Volumetric Water Content/Soil Moisture

Figure 7 shows volumetric water content of the four different treatment plots over time. Raw data collected by the SM150T meter in mV was converted to volumetric water content using a calibration equation determined from preliminary data. These data are likely to be revised upon development of an improved calibration curve. A graph of the raw data is provided in Appendix B. The data indicate all biochar amendments increased the water retention of the soils significantly, with the most significant effect observed for the Privet biochar.

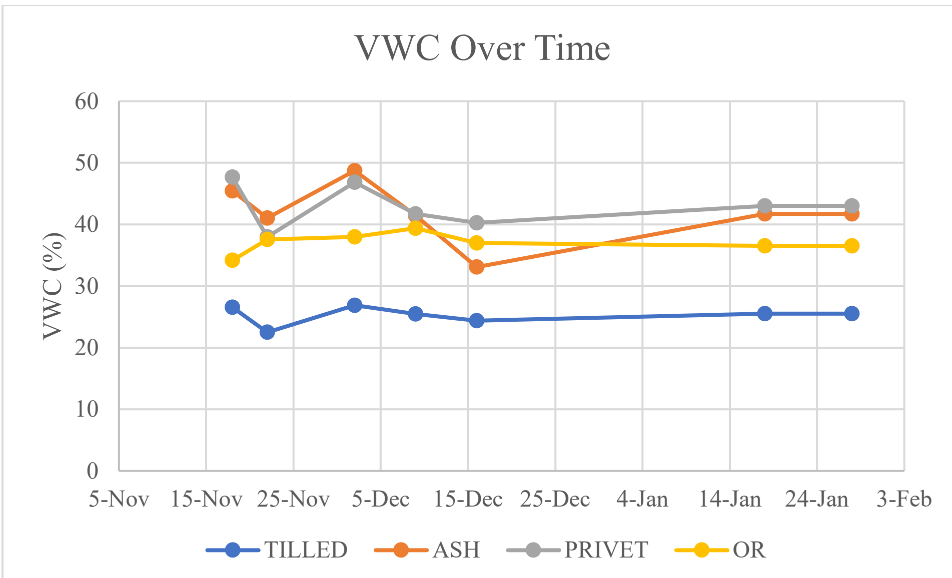


Figure 7: Volumetric Water Content (VWC) Over Time

Vegetation

Pictured below in Figures 8 and 9 are images showing the vegetation at each treatment plot in September and November. From the photographs, it is evident that there was significant vegetation growth between the September 2nd and the November 4th visits. In September, all treatment sites showed similar amounts of vegetation, however more straw had been removed from the OR plot than the others. In November, the tilled and OR plots showed slightly more vegetation than the Ash and Privet plots.

September

Figure 8: Vegetation in September

November

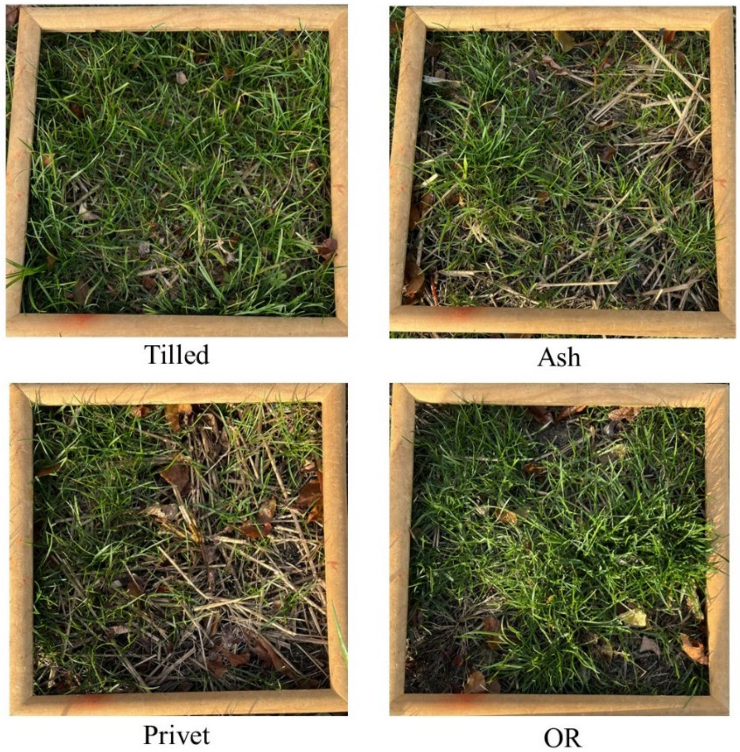


Figure 9: Vegetation in November

Field Capacity

The average field capacity for each treatment site determined from in-tact cores collected in November 2022 are shown in Figure 10. 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. Wilting point measurements are currently underway. With these measurements, plant available water, the difference between field capacity and wilting point, can be determined. We expect plant available water to be greater in the biochar-amended soils, given the above field capacity data. More plant available water allows better vegetation performance, thus enhancing soil structure and likely stormwater infiltration.

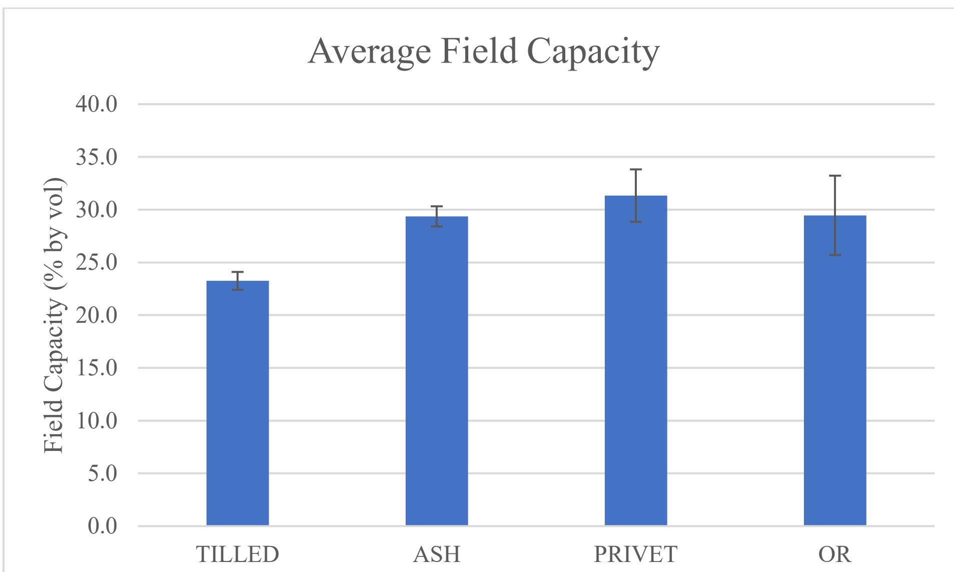


Figure 10: Average Field Capacity

FUTURE WORK

The data summarized above represent the initial performance of biochar amendment on soil structure and stormwater infiltration and retention with two kiln-produced biochars. Typically, rapid changes in soil structure from biochar amendment are expected in the first year after application. Thus, whether biochar will be beneficial can only be determined with measurements over longer periods. In the future, it is important to continue with field monitoring. The applied biochar will continue to change structure and alter soil characteristics over the next 2 years. Another field visit is planned for the end of February 2023, when more seasonal changes will be observed. This report summarizes the initial observations from this trial and more data is needed to understand the full performance of the tested biochars.

APPENDIX A: CALIBRATION CURVE PROCEDURE AND DATA

Full Procedure for TDR 150 and SM 150T calibration:

1. 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.
2. 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.
3. Measure out (by volume) the biochar and soil into aluminum pans and place in the oven at 105 C for 24 hours.
4. Remove pans from the oven, weigh pans, and record.
5. Measure the volume of the soil-filled region of the buckets using water displacement.
6. Weigh each empty container to know the starting mass.

For Control buckets:

7. Assume a dry bulk density of the native soil is 1.3 g/cm^3.
8. 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).
9. Measure out the dry mass of soil needed, increasing by 25% so that there is extra.
10. 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.

11. Weigh the fully packed container and record.
12. Weigh the remaining amount of dry soil that was not used in packing.
13. Subtract this amount from the total amount of dry soil weighed out to determine the amount of dry soil used in the container.
14. Repeat steps 6-12 for another replication.

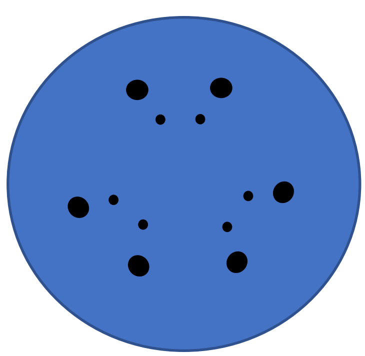
For Soil & Biochar mixed buckets:

15. 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%.
16. 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).
17. Given the biochar is 4% of the total mass in the container, calculate the dry mass of biochar needed.
18. Given the soil is 96% of the total mass in the container, calculate the dry mass of soil needed.
19. Measure out the dry masses of soil and biochar into separate buckets.
20. 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.
21. Pack the container according to step 9 and 10 above (using the moist soil and biochar mixture, not dry soil).
22. Place the remaining soil and biochar mixture into an aluminum pan and let dry in the oven for 24 hours at 105 C.

23. Weigh the remaining mixture and determine the total dry mass of biochar and soil in the containers.
24. Determine the actual dry bulk density of the soil/soil + biochar in the containers.
25. Place buckets in a large tote and propped up on PVC rings to allow water to enter through the holes in the bottom.
26. 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:

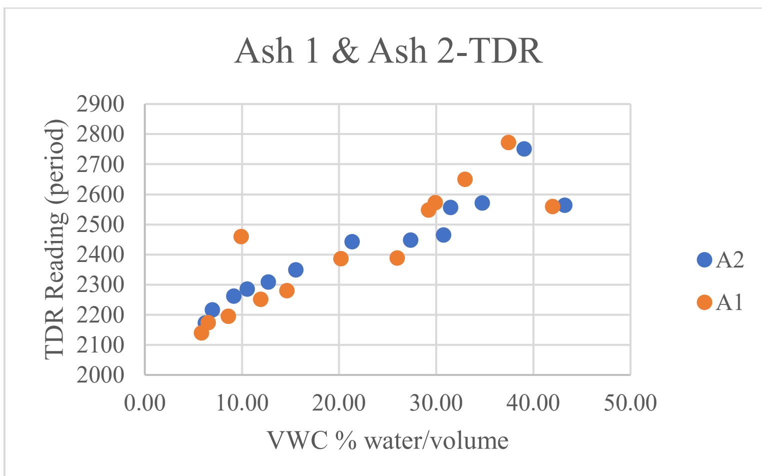
1. There should be water pooled on top of the soil to indicate complete saturation. If there is more than ½ inch of standing water above the soil, gently pour the water off the top of the bucket.
2. Remove the buckets from the tote and let drain from the bottom.
3. Carefully weigh the buckets while sitting 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:

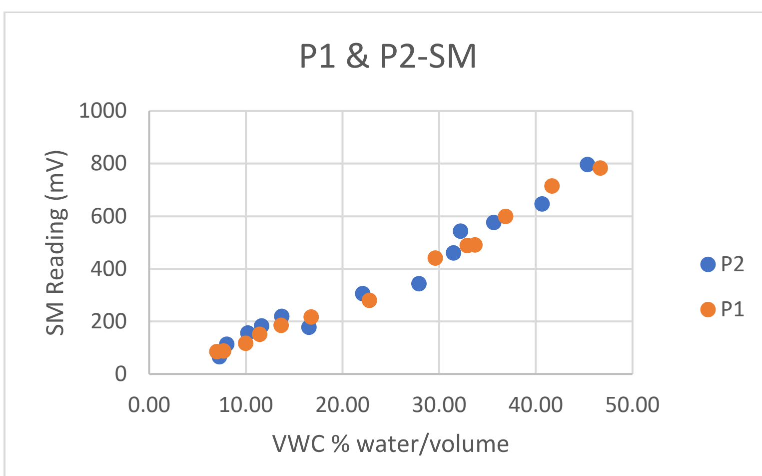


Larger holes indicate TDR150 probe; smaller holes are from the SM150T probe.

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: RAW SM150T DATA OVER TIME