Dare to be first.
UNIVERSITY OF DELAWARE

USBI BIOCHAR 2018
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Predicting Impact of Biochar on Soil Water Retention

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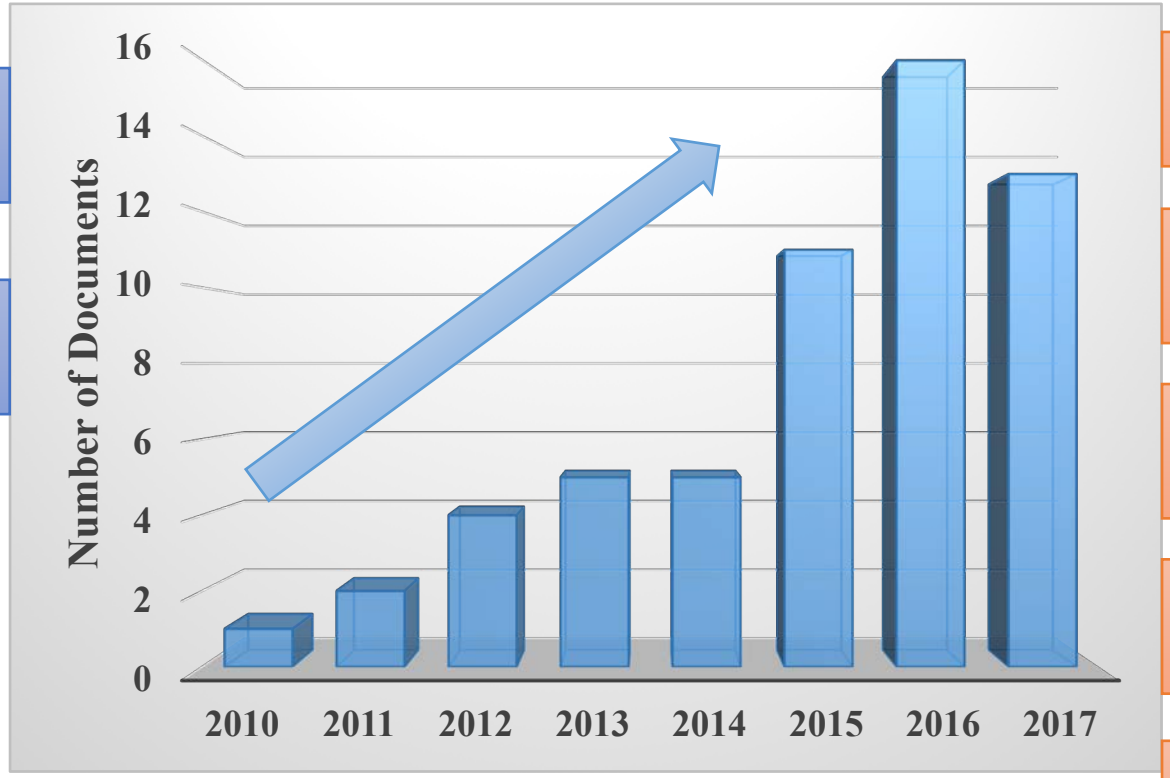
Direct Effect

Biochar Effect on Soil Hydrology

Indirect Effect

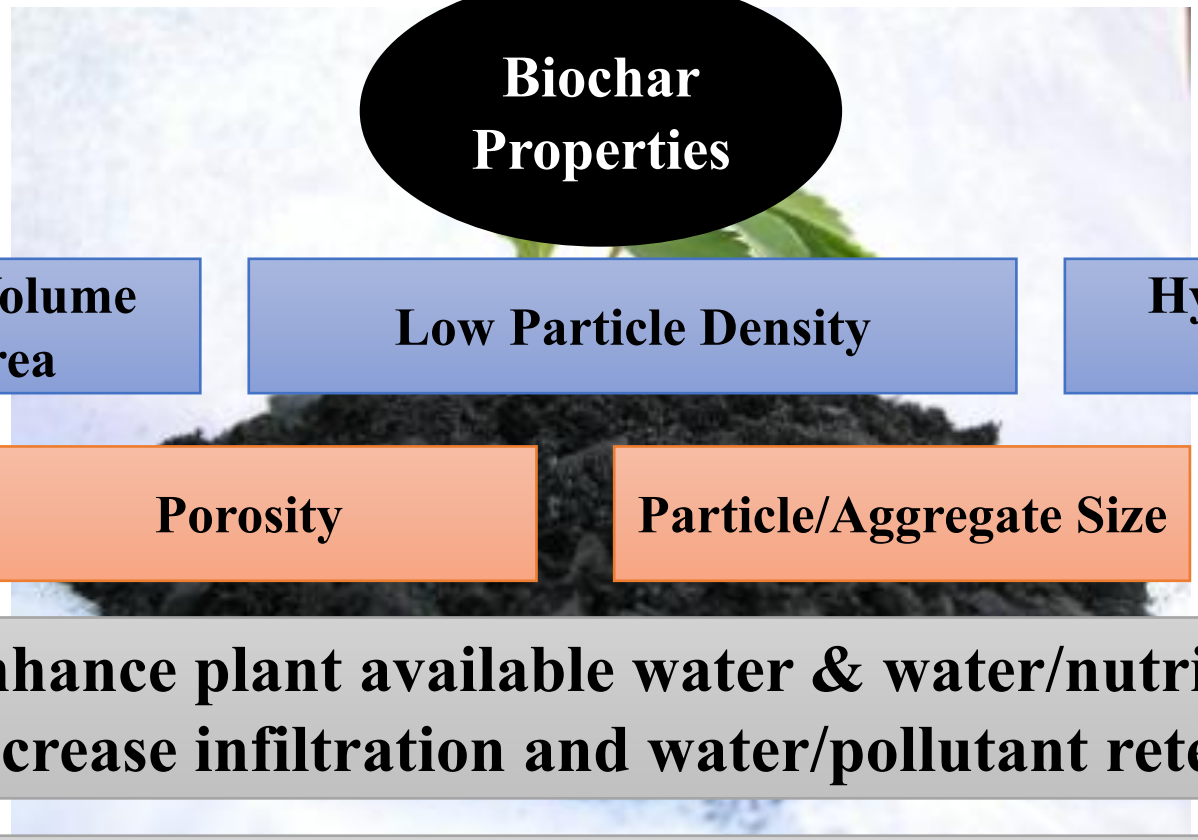
- Hydraulic Conductivity (Infiltration / Drainage)
- Water Retention Capacity
- Soil Hydrophobicity



https://www.scopus.com

- Soil Aggregation
- Soil Carbon Cycling
- Nutrient Availability
- Leaching of Solute
- Microbial Processes (Greenhouse Gas Production)
- Fungal Growth and Fauna Activity

Biochar Effect on Soil Hydrology



Biochar Properties

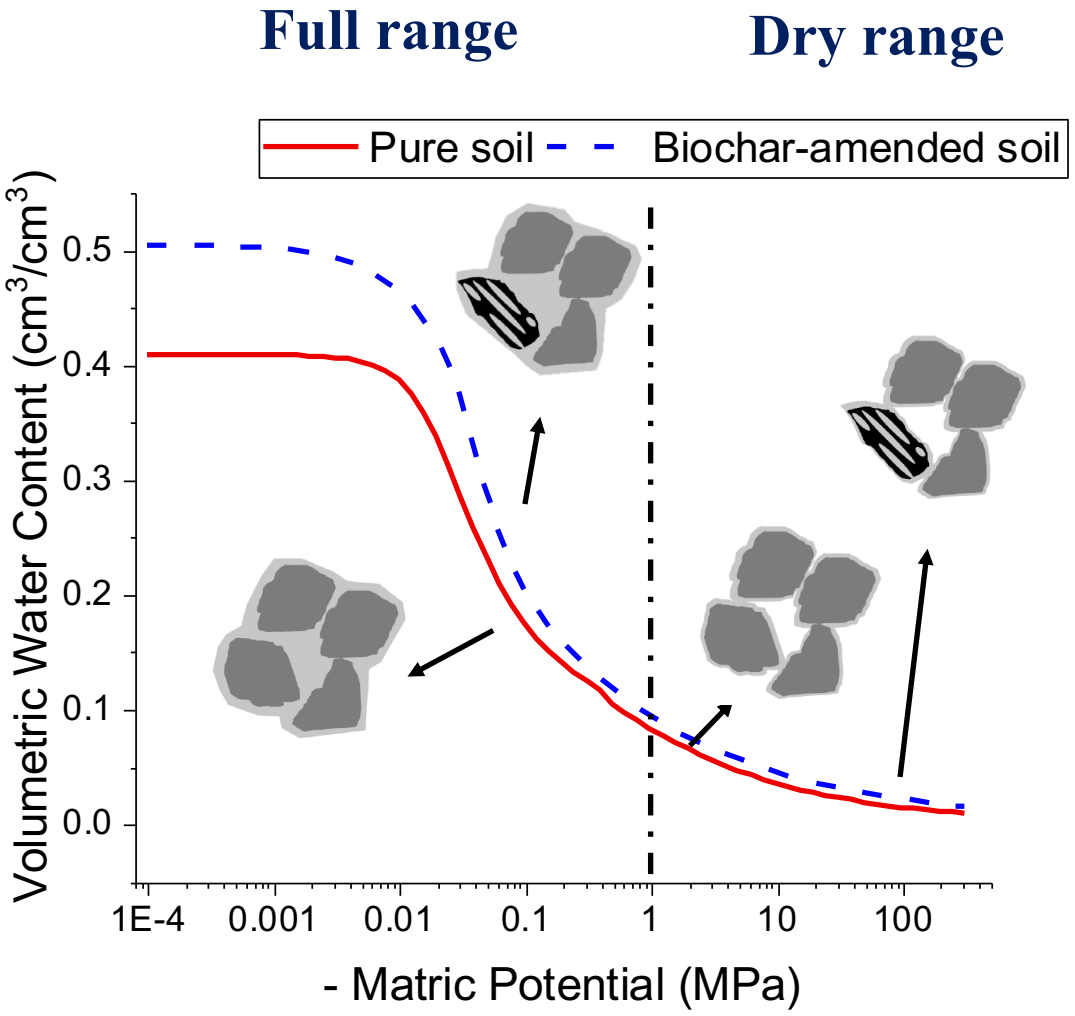
- Large Internal Pore Volume & High Surface Area
- Low Particle Density
- Hydrophobic/ Hydrophilic Surface

- Bulk Density
- Porosity
- Particle/Aggregate Size
- Surface Chemistry

- **<u>Agriculture:</u>** Enhance plant available water & water/nutrient use efficiency
- **<u>Stormwater:</u>** Increase infiltration and water/pollutant retention

- The impact varies with soil and biochar type (not always positive)
- No accurate predictive models yet
- Every soil/biochar combination must be tested to determine water retention - expensive and time consuming!

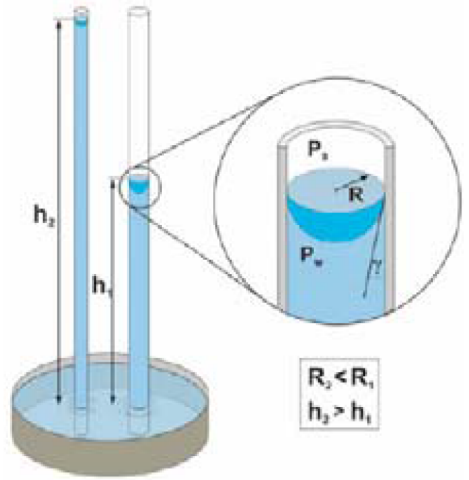
Biochar Impact on Soil Water Retention Curve (WRC)



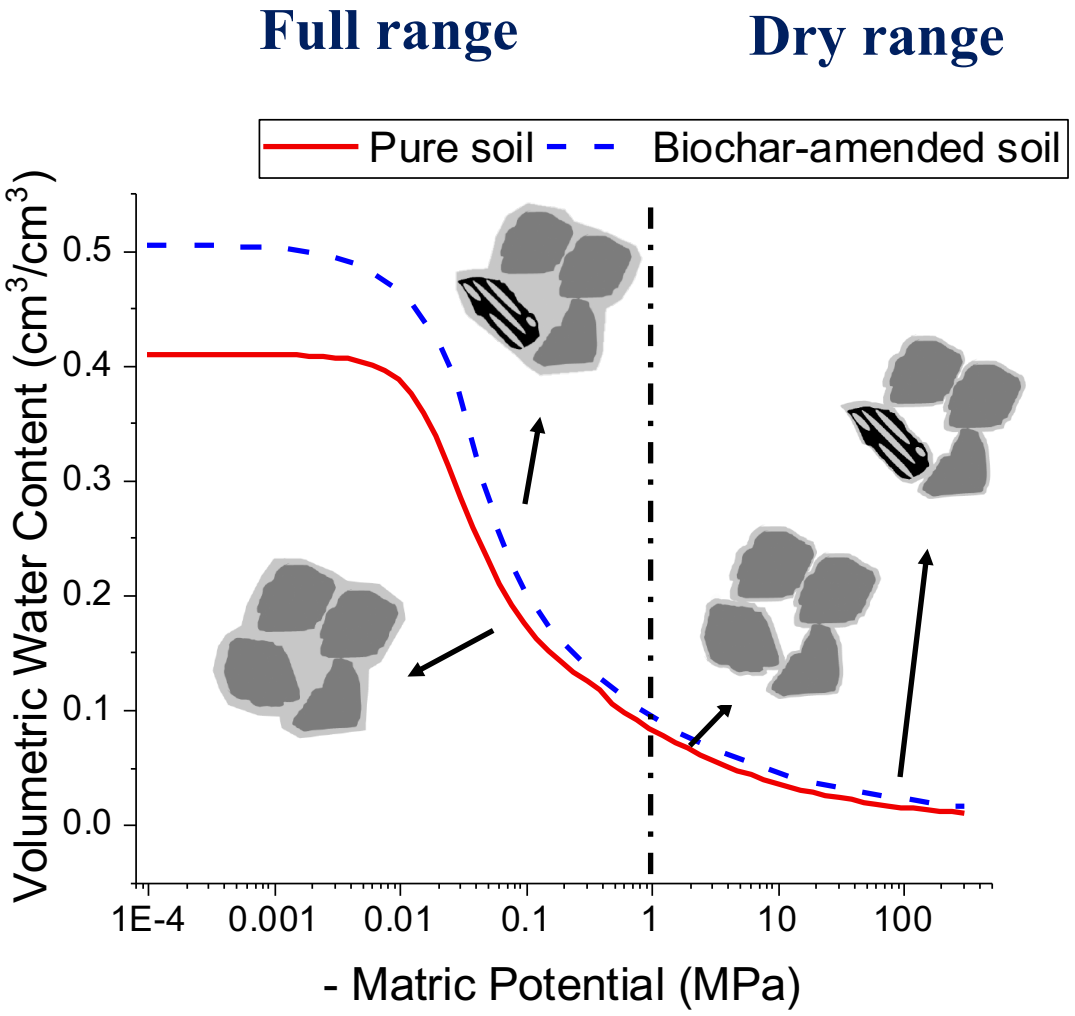
➢ **Full range:**

- **Pore space between particles (inter porosity)**
- **Biochar internal pore volume (intra porosity)**

$$h = \frac{2\sigma \cos\gamma}{\rho_w g R}$$



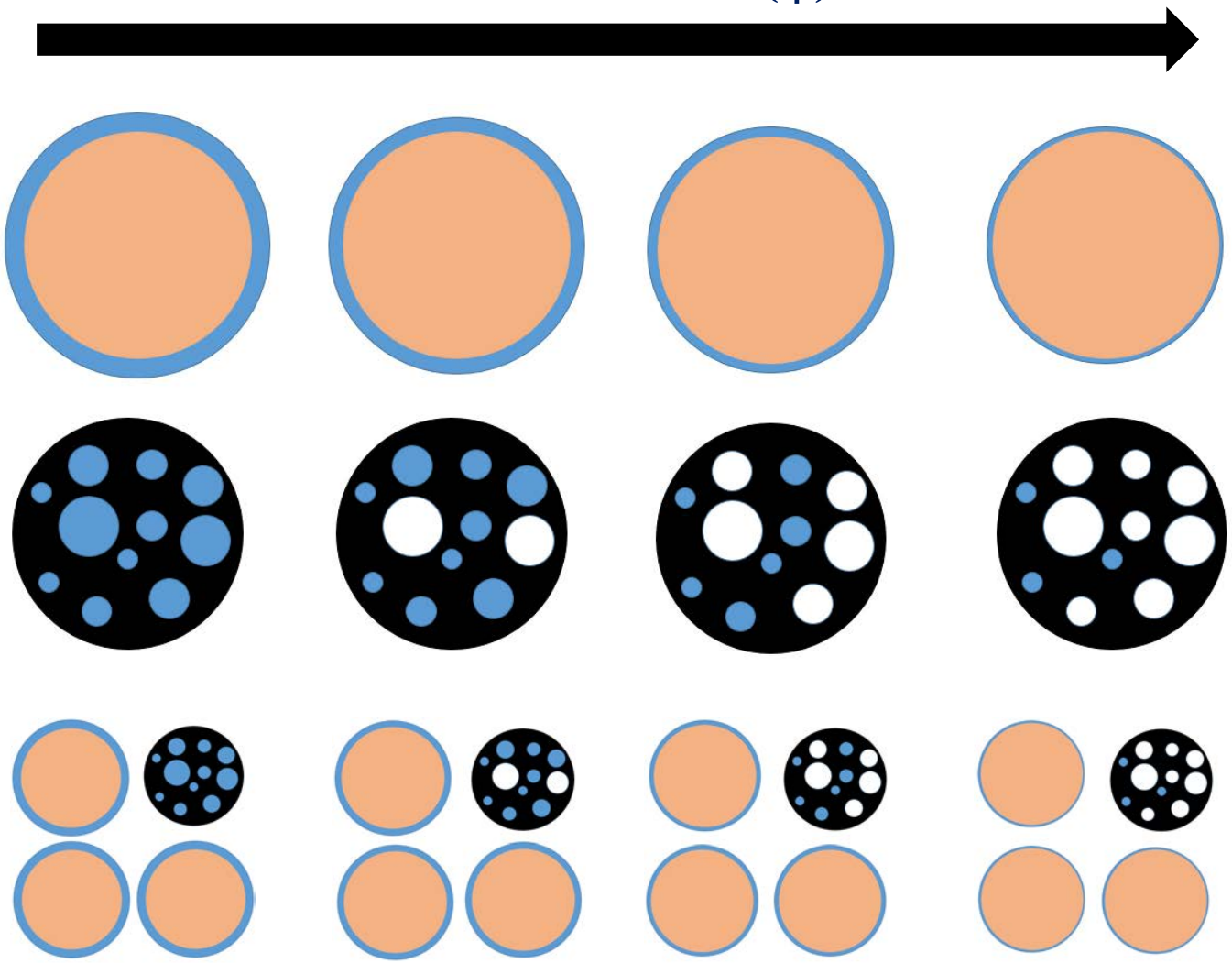
Biochar Impact on Soil Water Retention Curve (WRC)



- **Soil Water Retention Curve**
  - **Water content vs. matric potential**
- **Matric Potential**
  - **Capillary and adsorptive forces**
  - **Surface tension**
- **Dry range:**
  - **Soil surface area**
  - **Biochar internal meso and micropore volume**

Dry Range of WRC

- Matric Potential (ψ)



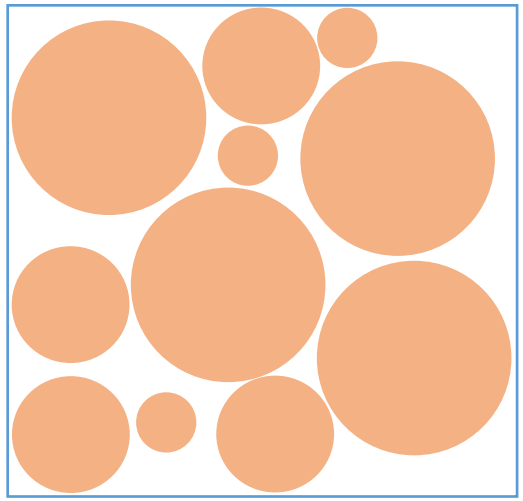
$$thickness\ (t)_i \propto \left(\frac{1}{\psi}\right)^{1/3}$$ ***Tuller and Or (2005)***

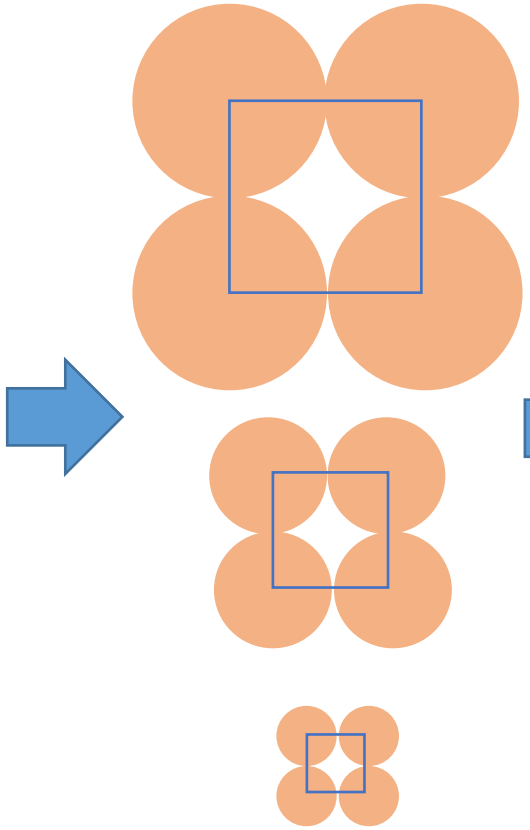
$$moisture\ content\ (MC)_i^s = \rho_w \times surface\ area_s \times t_i$$

$$MC_i^b = \rho_w \times \sum_{j=1}^{i} pore\ volume_j$$

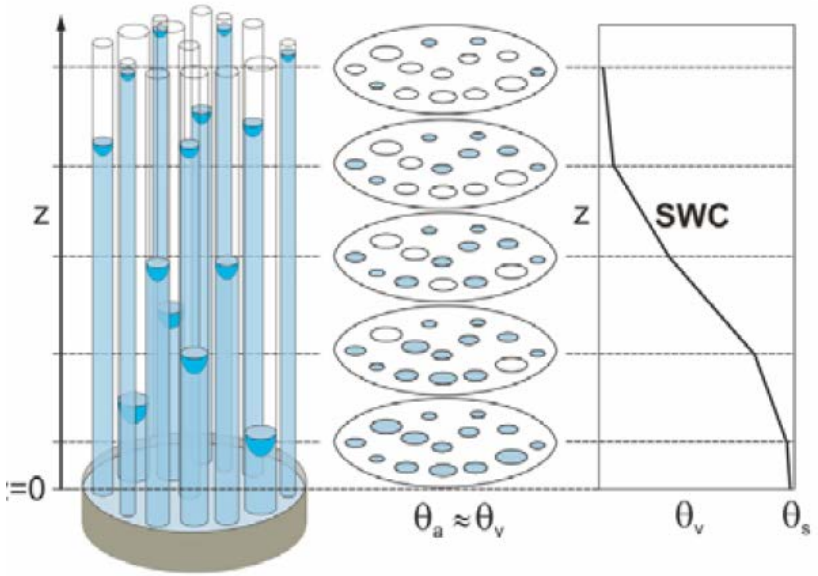
$$MC_i^m = biochar\ content \times MC_i^b + soil\ content \times MC_i^s$$

Full Range of WRC: Soil Alone





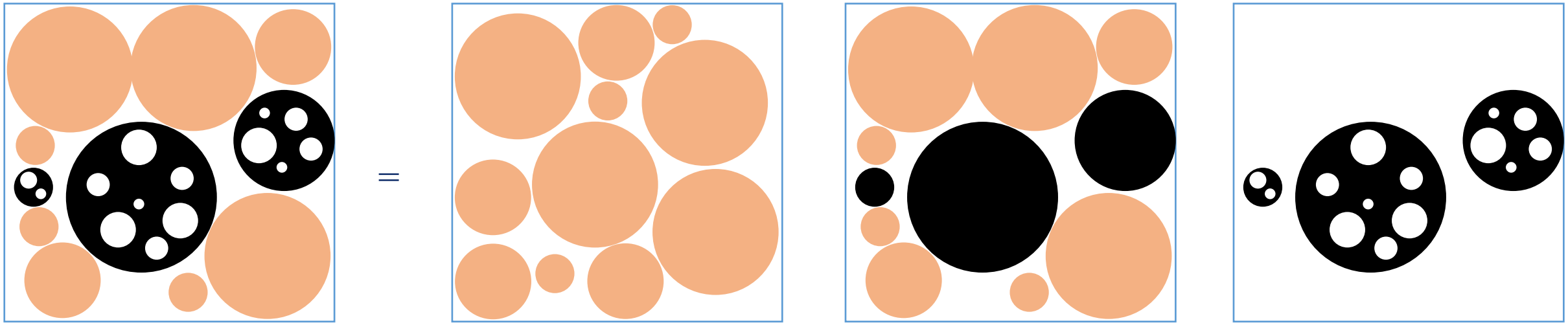
- $pore\ radii \propto particle\ radii$
- $water\ potential \propto \frac{1}{Pore\ Radii}$
- $water\ content \propto$ pore volume
- Input:
  - Particle size distribution
  - Bulk density
  - Particle density



Arya and Paris, 1981; Arya and Heitman, 2015

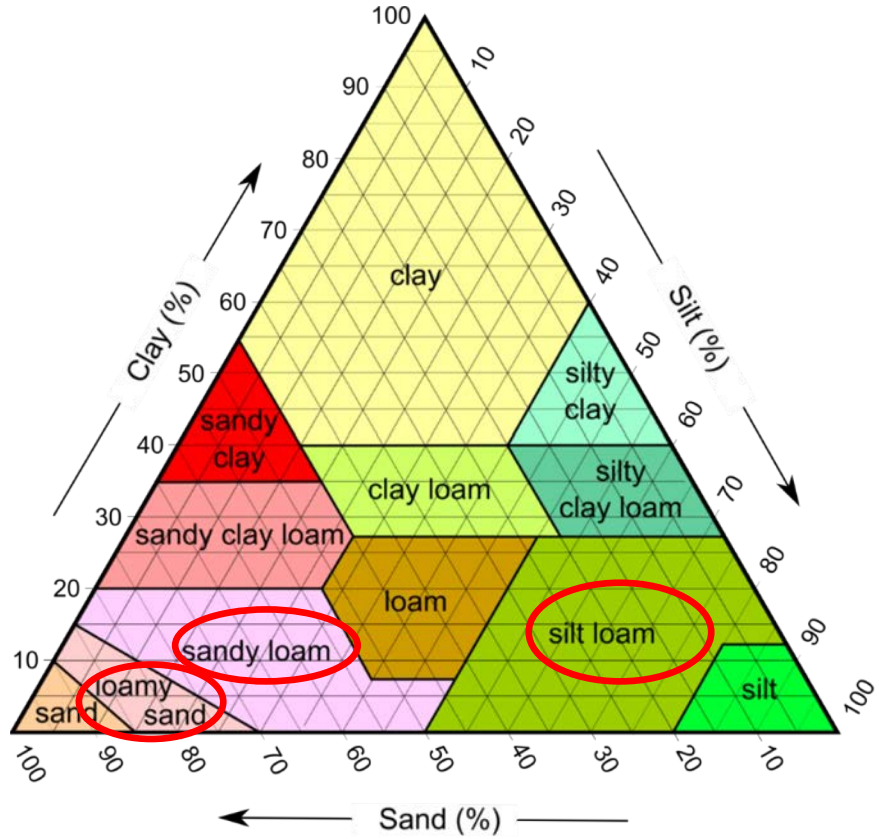
Full Range of WRC: Soil + Biochar

Biochar-amended Soil = Soil + Δ Inter Porosity + Δ Intra Porosity



Method – Soil & Biochar & WRC Measurements

- Biochar
  - Soil Reef™ (The Biochar Company)
  - Rinsing biochar to remove hydrophobicity
- Soils
  - Silt loam, sandy loam, & loamy sand
- Mixture
  - 2 & 6% w/w biochar



- WRC measurement
  - Dry range: WP4C (Decagon)
  - Wet Range: Hyprop (Decagon)

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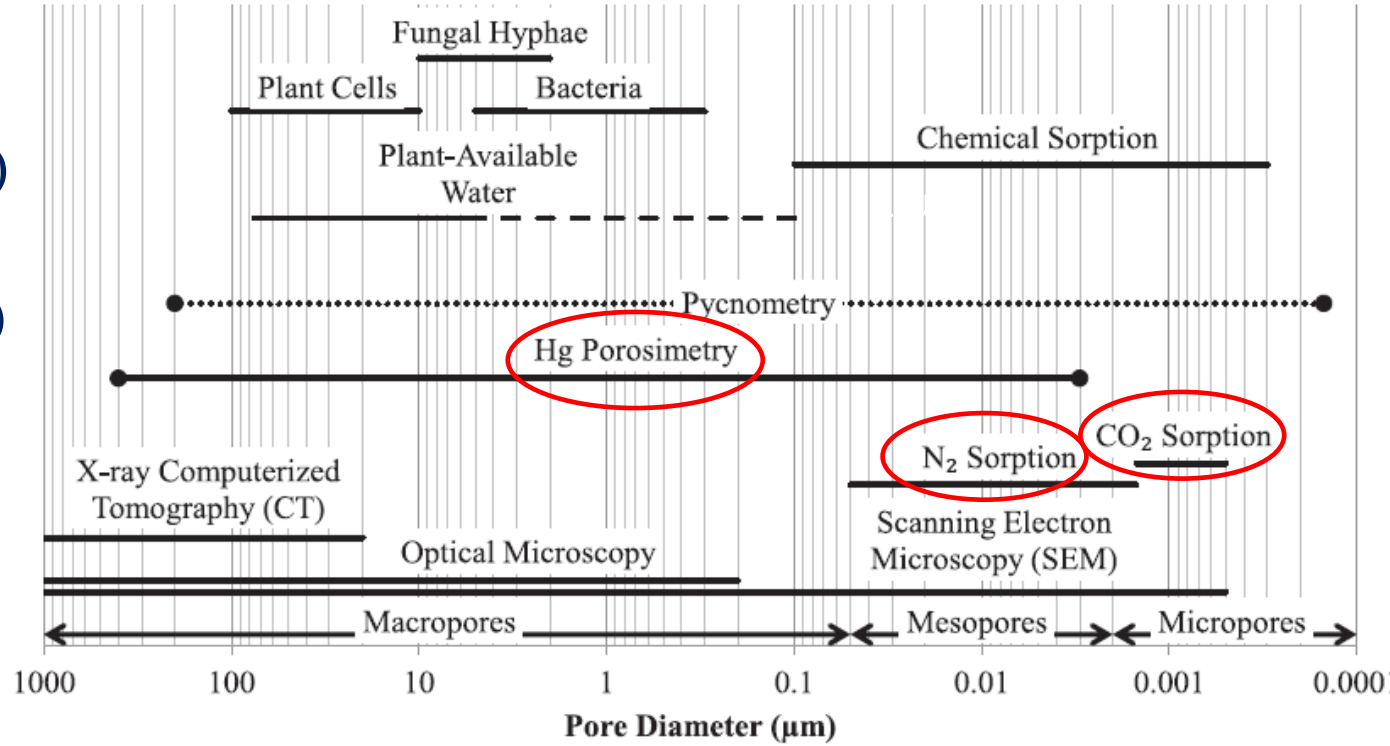
Method – Soil & Biochar Characterization

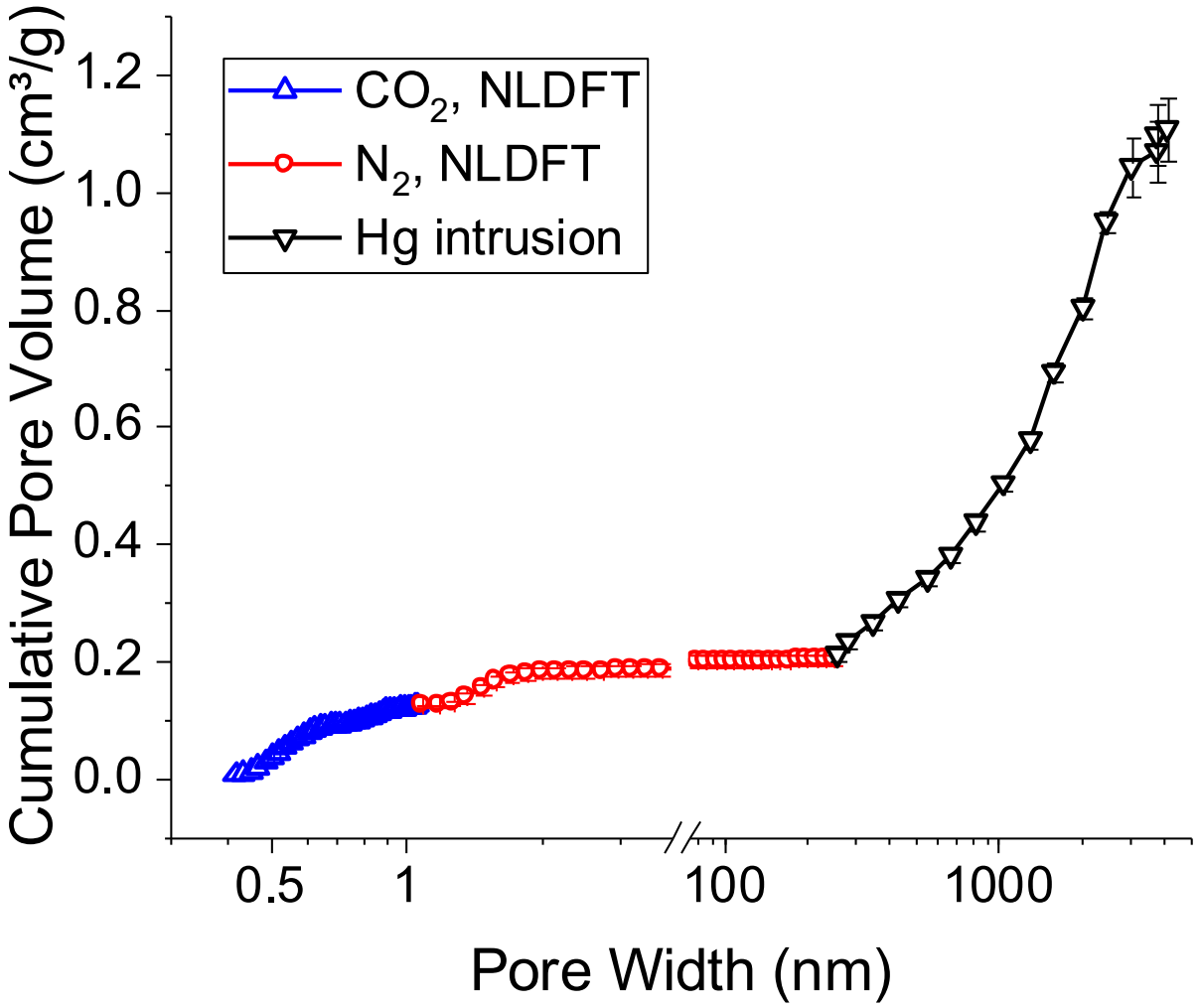
- Biochar intra pore size distribution
  - Quantitative
    - ✓ Hg porosimetry
    - ✓ N2 and CO2 sorption
      (Non-local Density Functional Theory)
  - Qualitative
    - ✓ Electron microscopy (SEM & TEM)

- Soil surface area
  - EGME
    (Ethylene Glycol Monoethyl Ether)

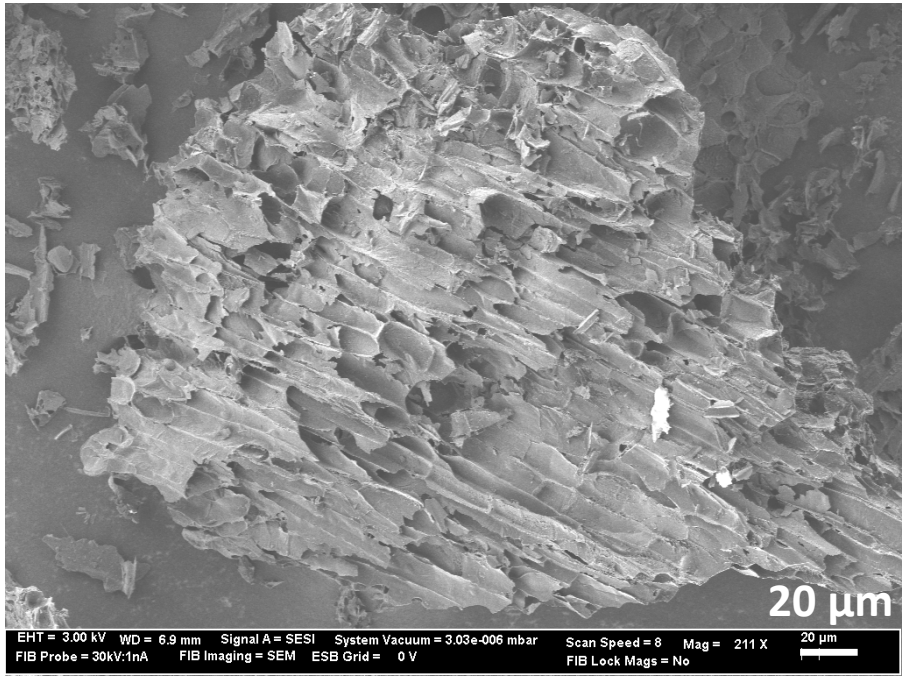
- Particle size distribution
  - Sieve + hydrometer analyses

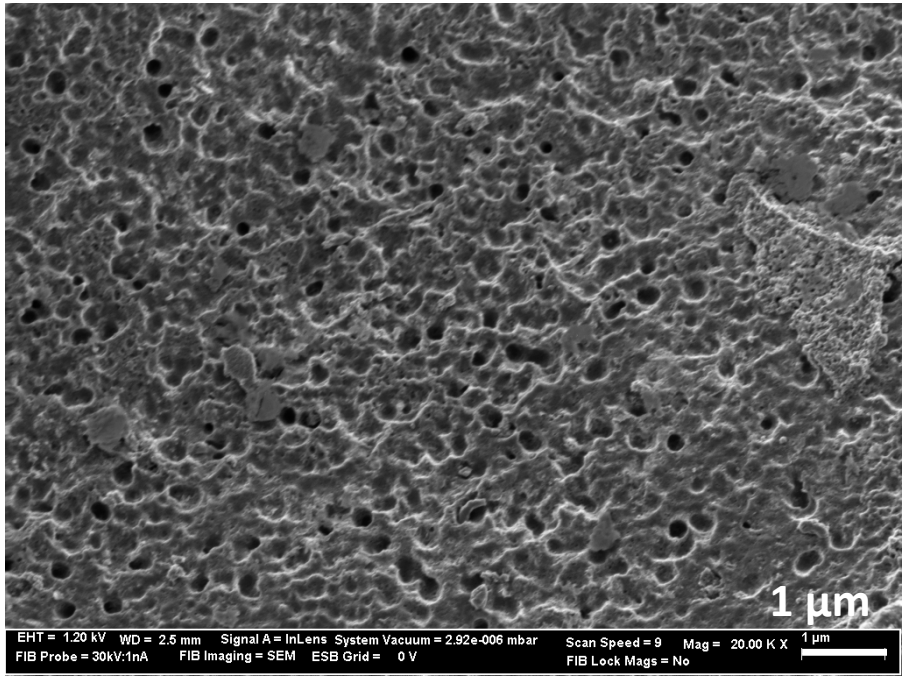


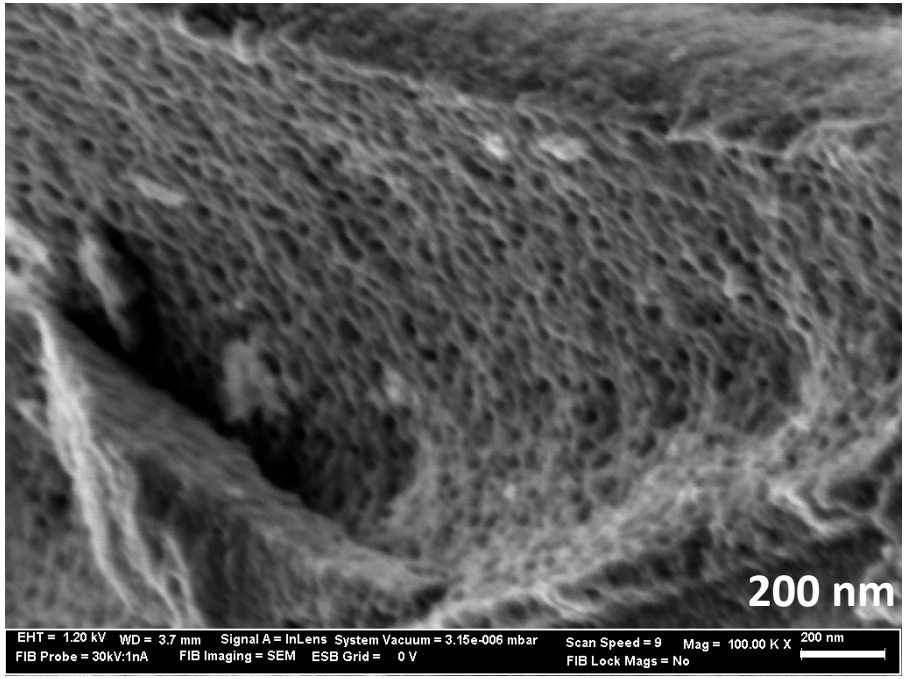
Results – Biochar Internal Porosity

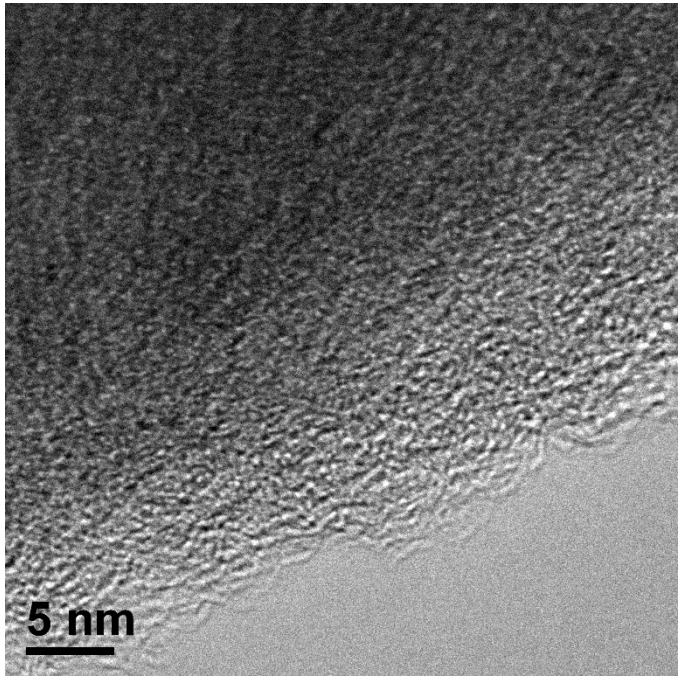


- Intra pore width
  0.4 nm – 4.13 µm
- Intra pore volume
  1.11 ± 0.05 cm^3/g
- Envelope density
  0.52 ± 0.02 g/cm^3
- Skeletal density
  1.23 ± 0.11 g/cm^3

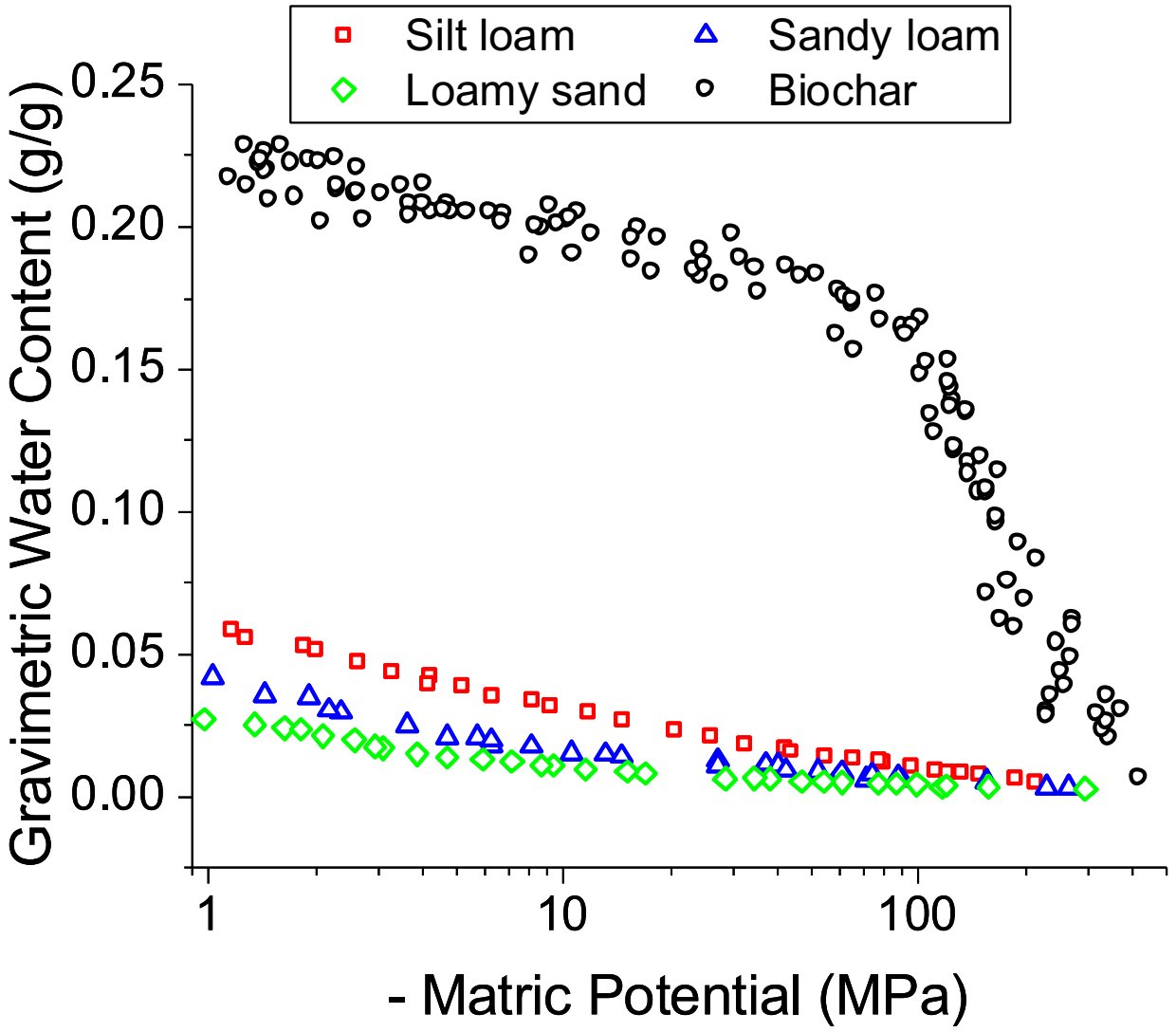

20 µm
EHT = 3.00 kV WD = 6.9 mm Signal A = SESI System Vacuum = 3.03e-006 mbar
FIB Probe = 30kV:1nA FIB Imaging = SEM ESB Grid = 0 V
Scan Speed = 8 Mag = 211 X 20 µm
FIB Lock Mags = No


1 µm
EHT = 1.20 kV WD = 2.5 mm Signal A = InLens System Vacuum = 2.92e-006 mbar
FIB Probe = 30kV:1nA FIB Imaging = SEM ESB Grid = 0 V
Scan Speed = 9 Mag = 20.00 K X 1 µm
FIB Lock Mags = No


200 nm
EHT = 1.20 kV WD = 3.7 mm Signal A = InLens System Vacuum = 3.15e-006 mbar
FIB Probe = 30kV:1nA FIB Imaging = SEM ESB Grid = 0 V
Scan Speed = 9 Mag = 100.00 K X 200 nm
FIB Lock Mags = No

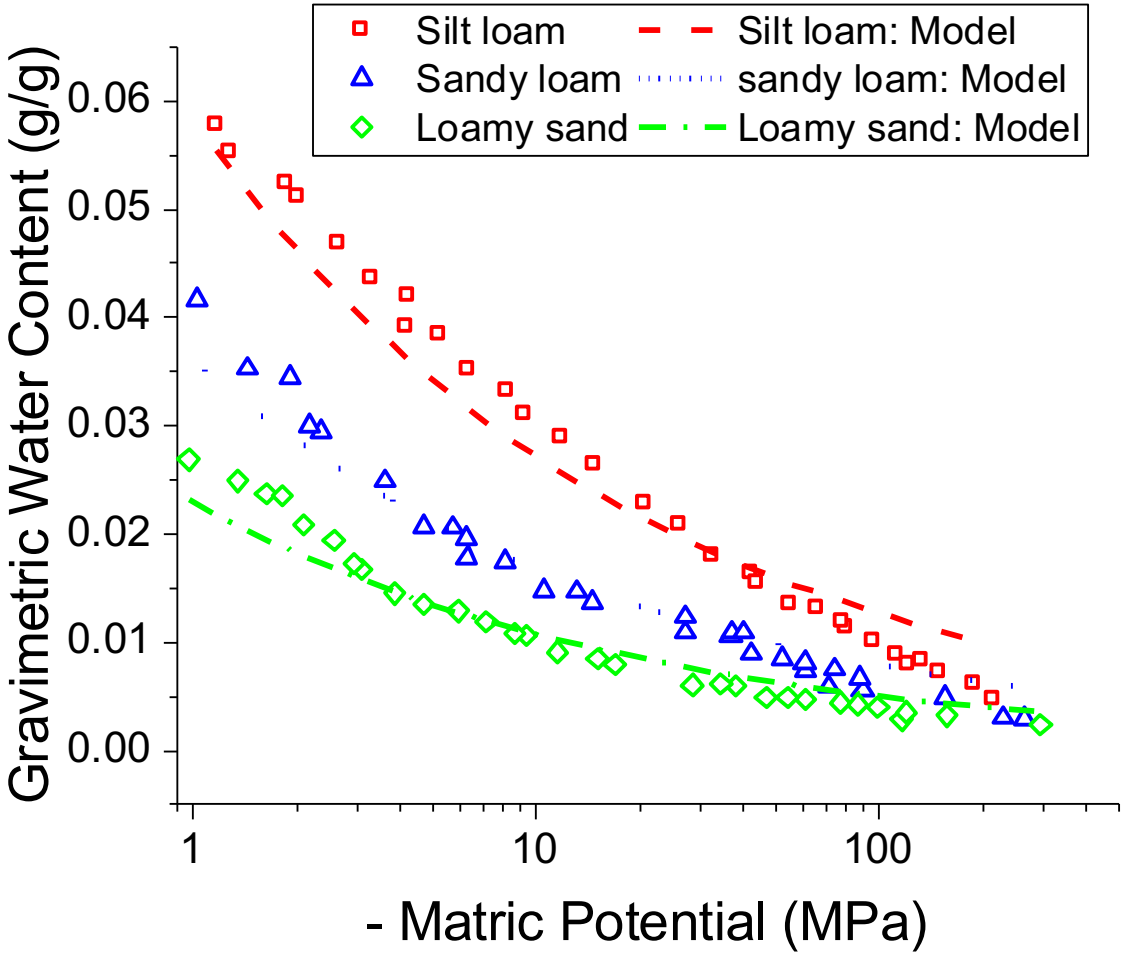

5 nm

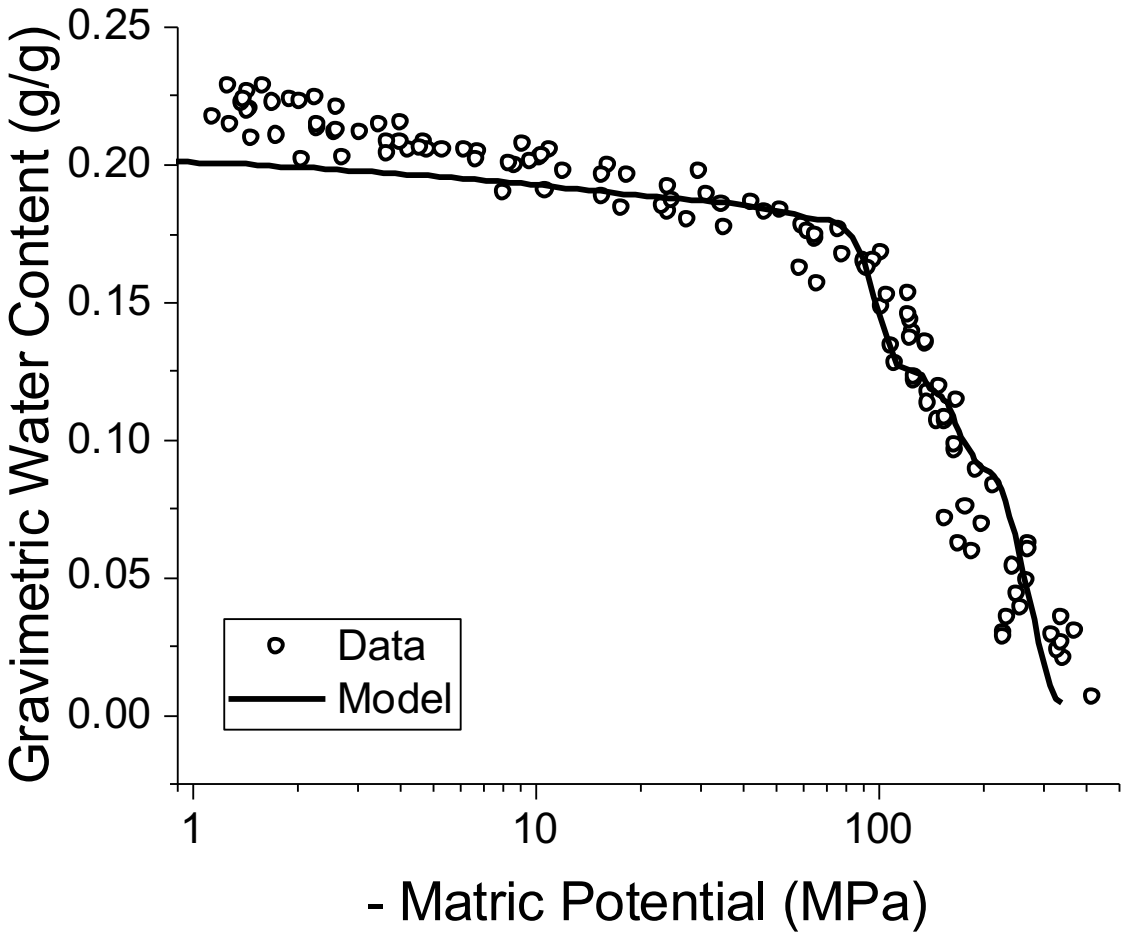
Results – WRC (Dry Range)



- Higher water content for finer soils
- Biochar
  - Significantly higher water content
  - Different curvature

Model – WRC (Dry Range)

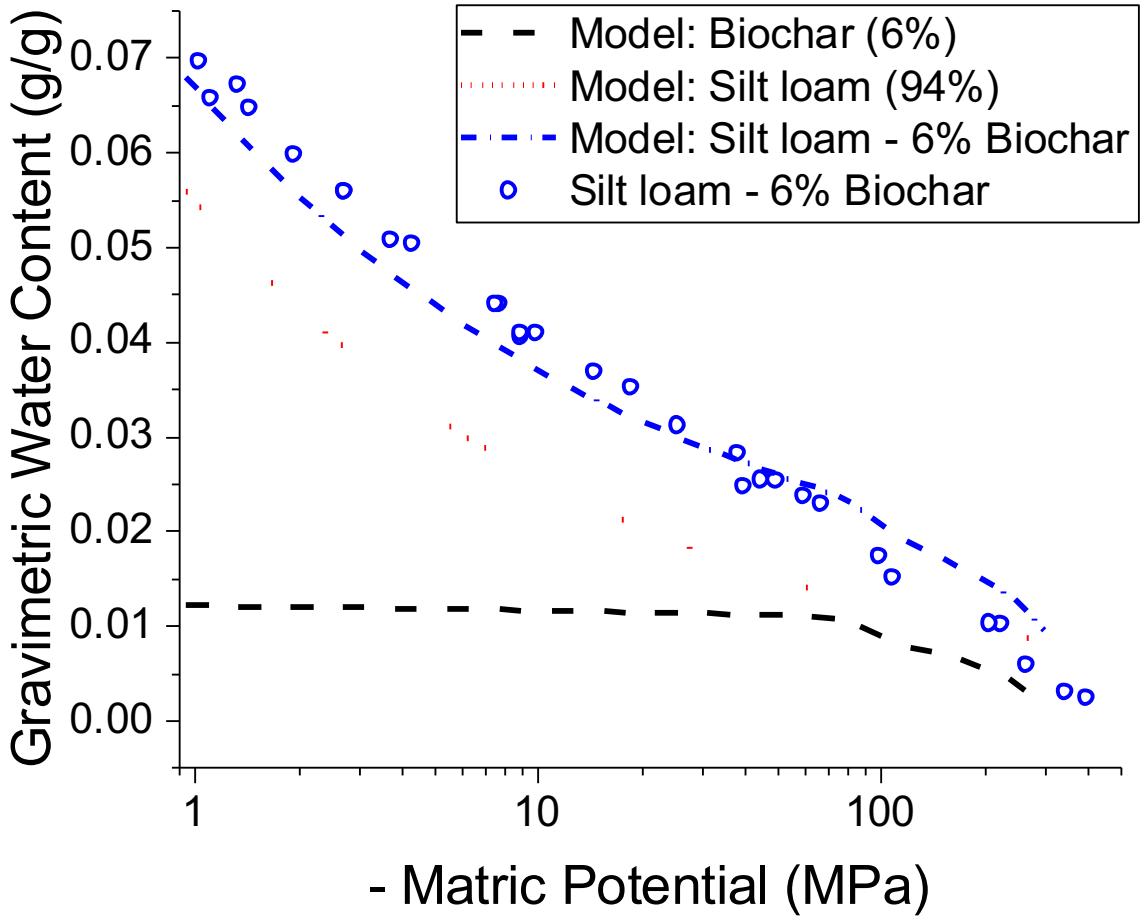




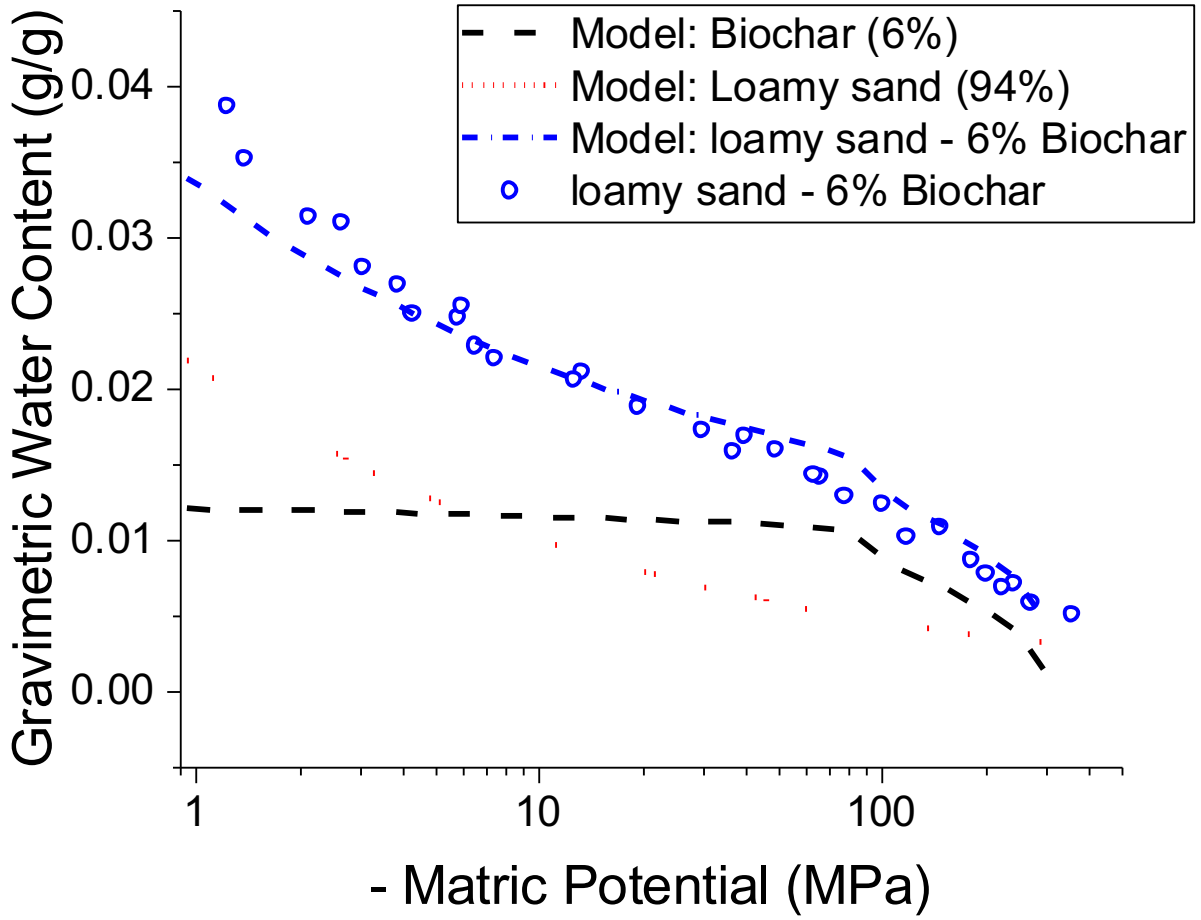
- Predictive model using EGME surface area
- Predictive models using CO_2 and N_2 sorption isotherm

Model – WRC (Dry Range)

Silt loam + 6% Biochar

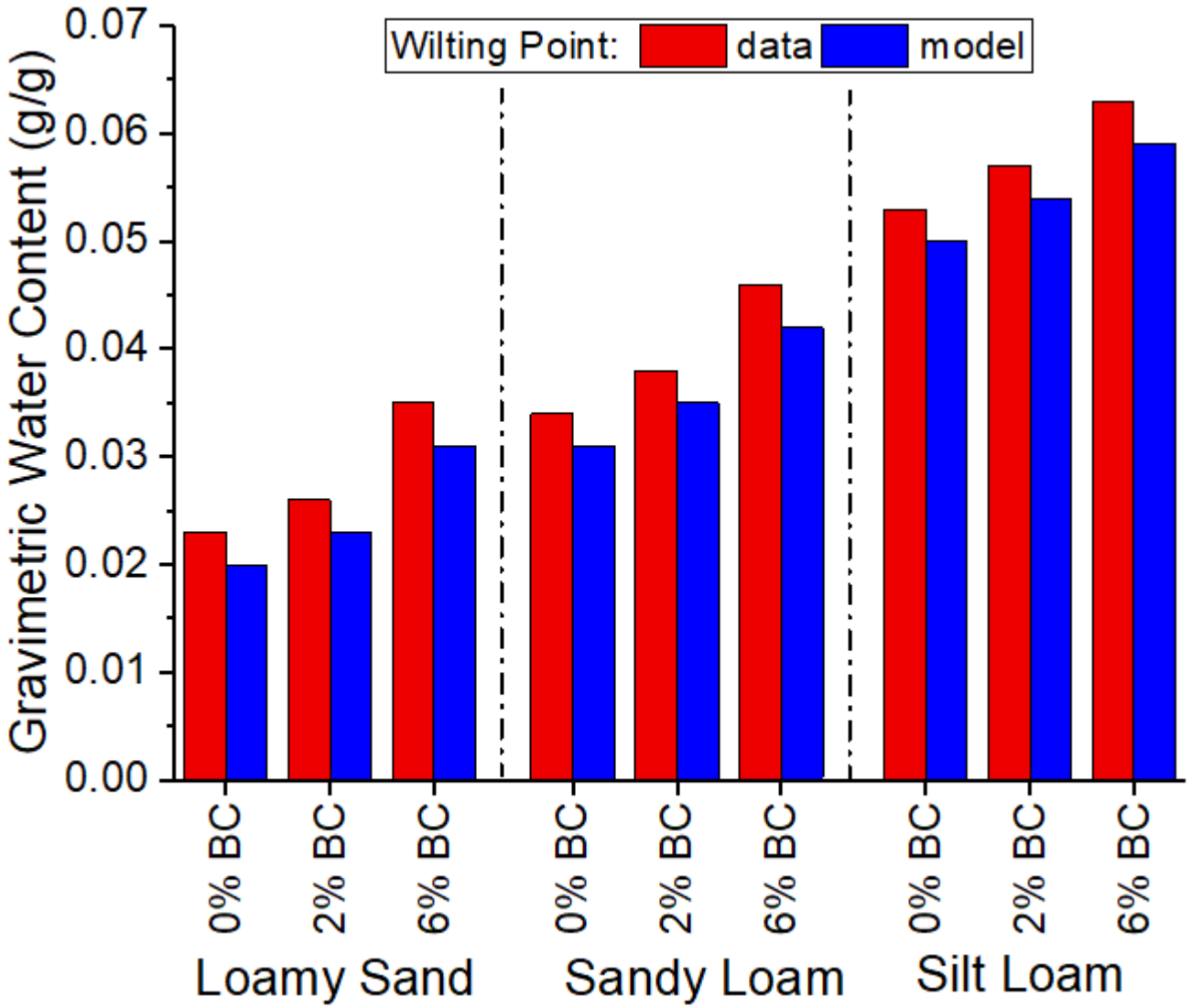


Loamy sand + 6% Biochar



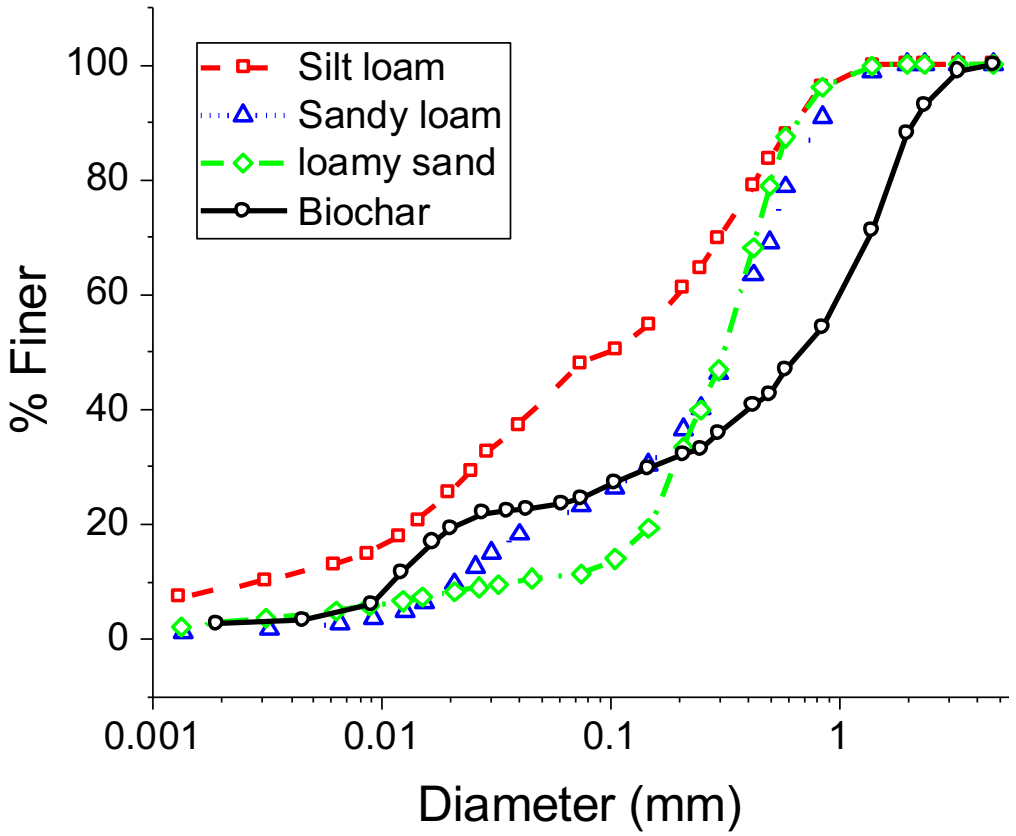
- Predictive model based on mass balance

Model – WRC (Dry Range)

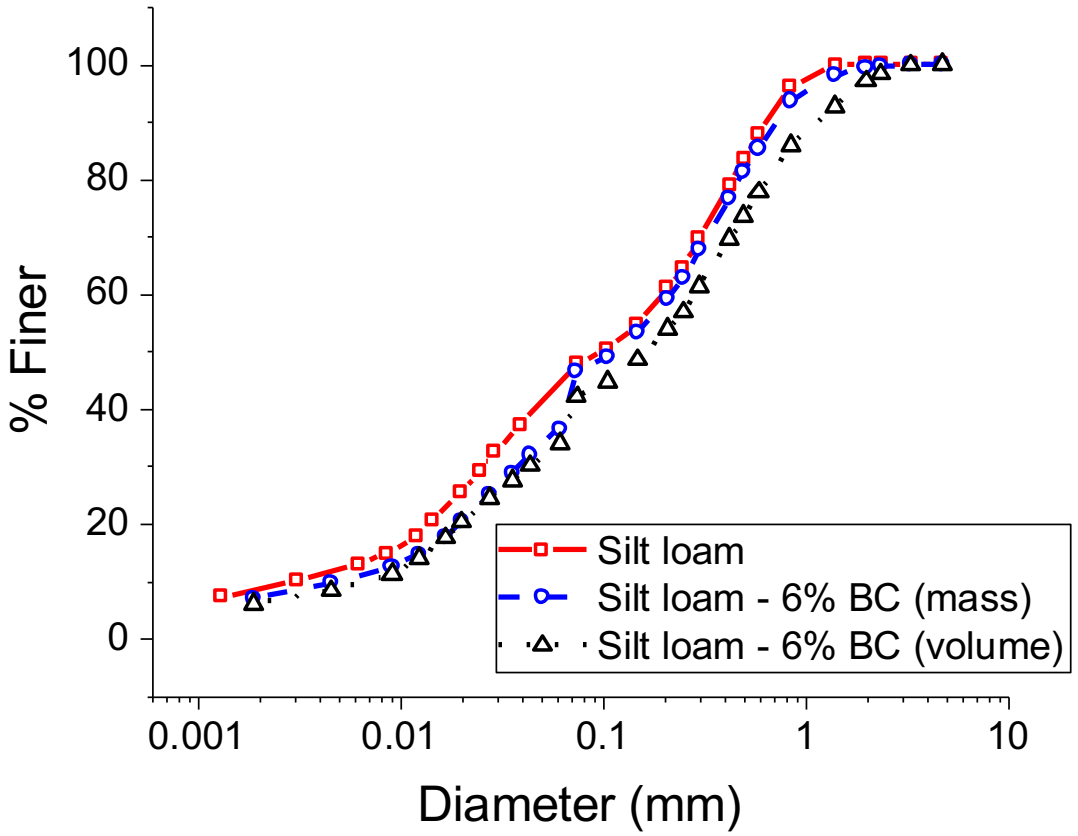


Results – Particle Size Distribution

All soils and biochar

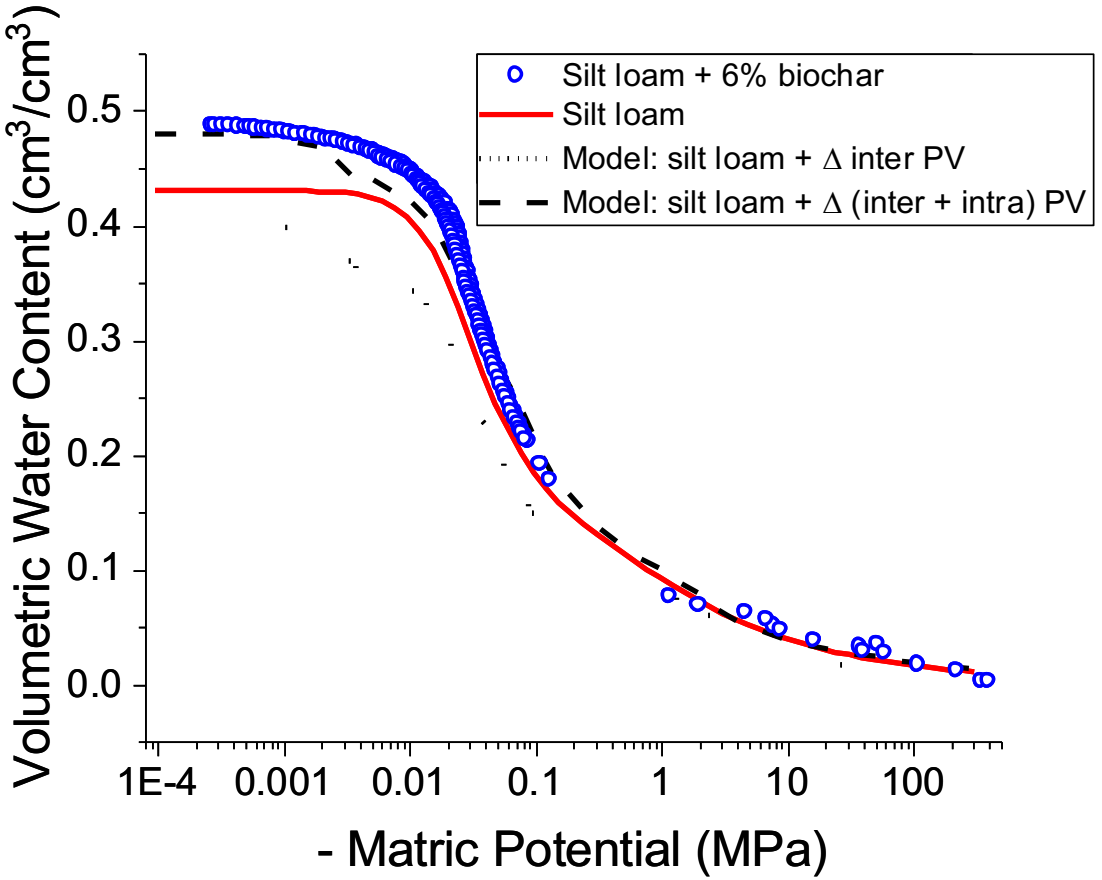


Silt loam + 6% biochar

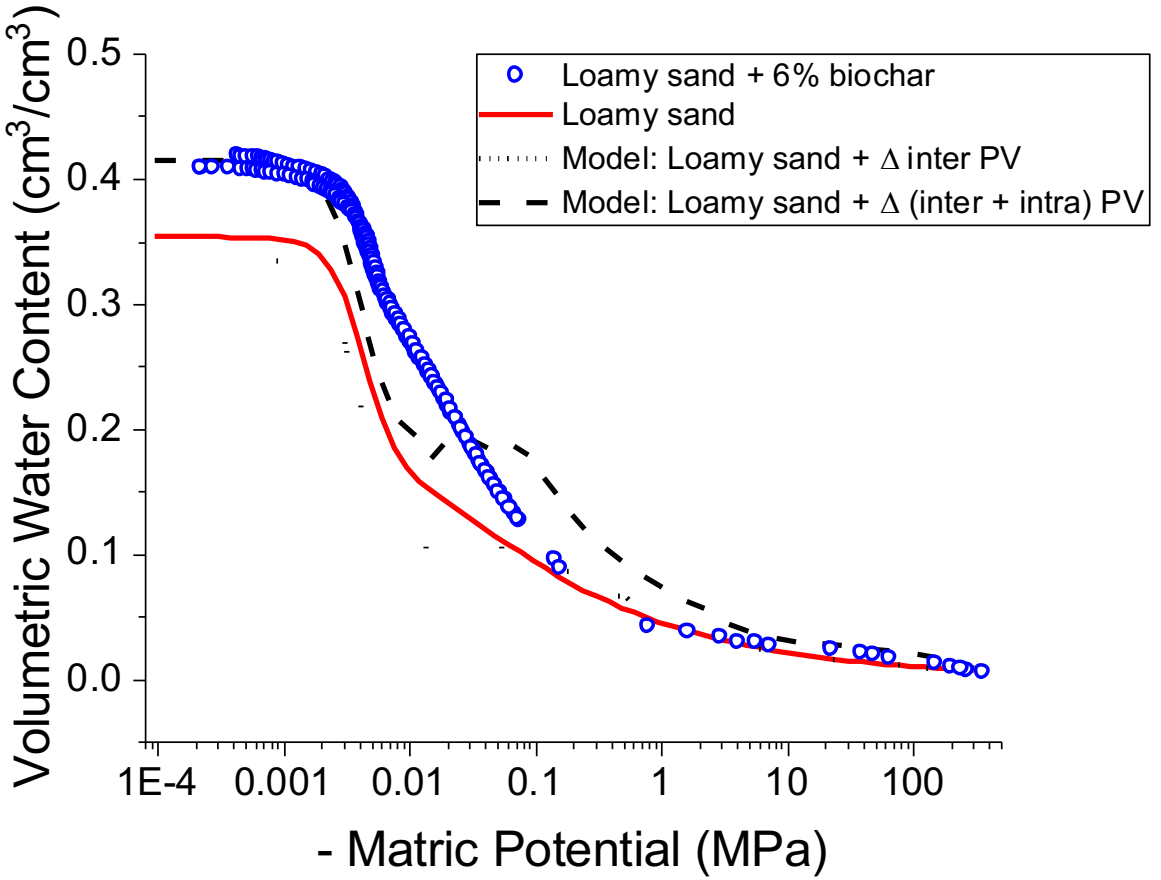


Model – WRC (Full Range)

Silt loam – 6% BC (best case!)



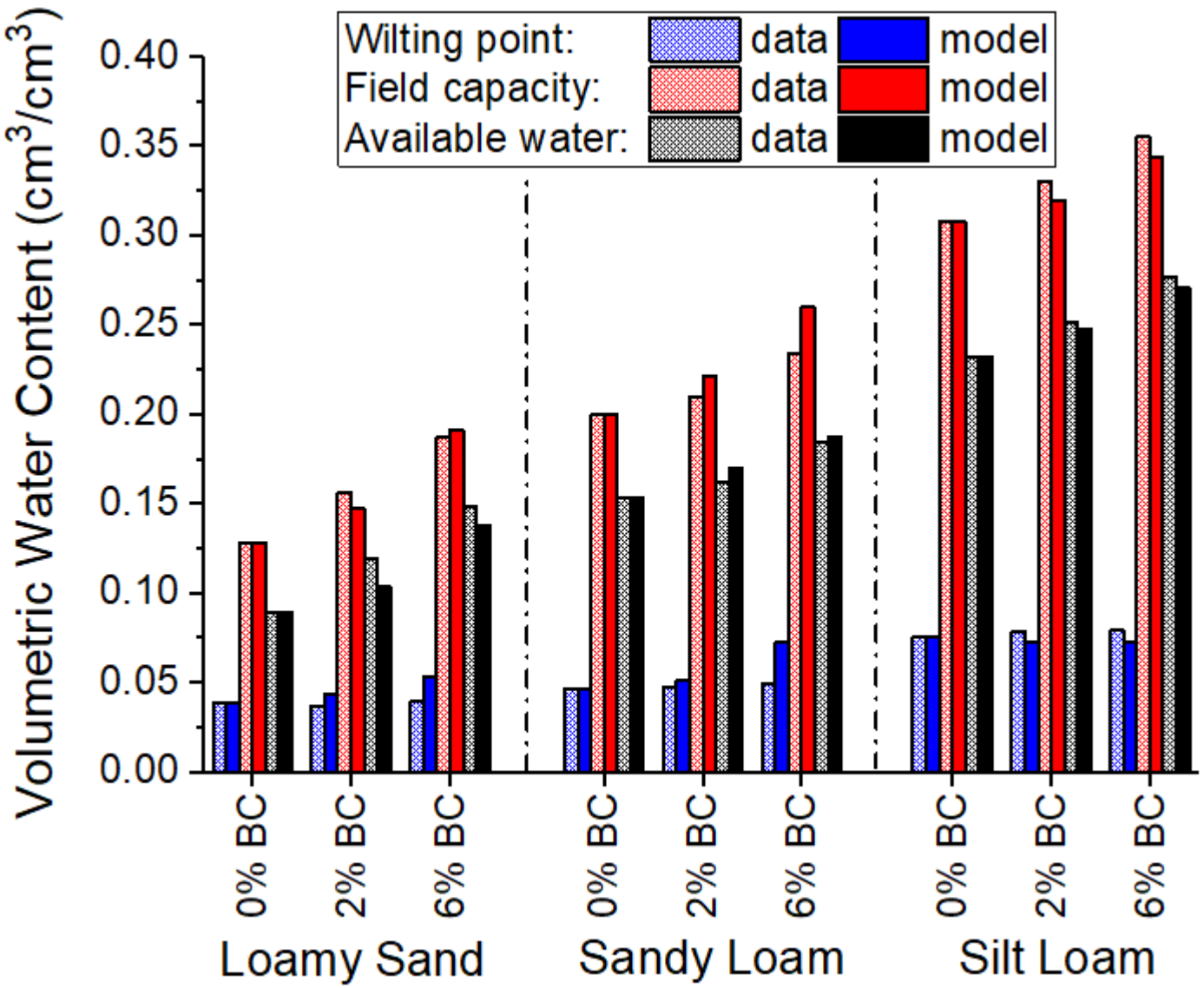
Loamy sand – 6% BC (worst case!)



- Model works better for finer soils

- The problem is using PSD as input to predict change in inter pore volume

Model – WRC (Full Range)



Summary

- Biochar impact on soil WRC can be predicted rather then measured
  - Dry range model:
    - ✓ Permanent wilting point
  - Full range model:
    - ✓ Field capacity, permanent wilting point, & available water content

- Predictive models use soil and biochar physical properties
  - Dry range model input:
    - ✓ Soil surface area, biochar internal micro and meso pore size distribution
  - Full range model input:
    - ✓ Soil & biochar particle size distribution, biochar internal pore size distribution, bulk & particle densities

- Models developed for repacked soil and do not consider
  - Aggregate formation
  - Biochar aging