NC STATE UNIVERSITY
DEPARTMENT of **SOIL SCIENCE**

Biochar Improved Agronomically Important Physical Properties in a Coastal Plain Ultisol

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COLLEGE OF AGRICULTURE & LIFE SCIENCES
ACADEMICS ▲ RESEARCH ▲ EXTENSION

Rationale

Many agriculturally important soils in North Carolina's Coastal Plain are coarse-textured sandy, loamy-sand, and sandy-loam Ultisols developed in residuum of ancient marine and fluvial deposits. These would include the Norfolk, Noboco, Goldsboro and related series having low C content, CEC, acid pH, aggregate stability, infiltration, water holding capacity, and high exchangeable Al. It is difficult to increase C levels within the shallow 0-0.20 m deep Ap horizon due to rapid oxidation of crop residue from high annual temperature and rainfall, particularly under intensive clean cultivation of row crops like cotton and corn. Further, certain Coastal Plain soils develop high strength E horizons 0.20-1 m deep that require annual deep ripping to remain productive, an energy intensive tillage operation that could be mitigated by C enrichment. One type of C that may alleviate root zone chemical and physical handicaps in Coastal Plain soils is ***biochar***.

What is Biochar?

- Biochar is the charcoal remains of incomplete combustion of biomass such as woodchips, brush, crop residues, or green waste.
- Unlike the structural C found in organic materials such as manure and crop residue (**Figure 1**), most of biochar's C is in aromatic compounds that are resistant to decay (**Figure 2**).
- Biochar contains about 50% of the original C in biomass, with the balance driven off as biofuel products.
- It can be produced by pyrolysis or torrefaction, e.g., heating biomass under low O_2 concentration to extract biofuels (**Figures 3a,b**).
- Biochar production is carbon-negative, an environment friendly practice.

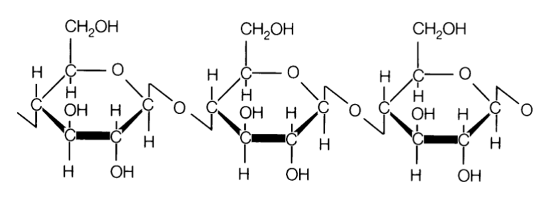


Figure 1. Structural cellulose-C

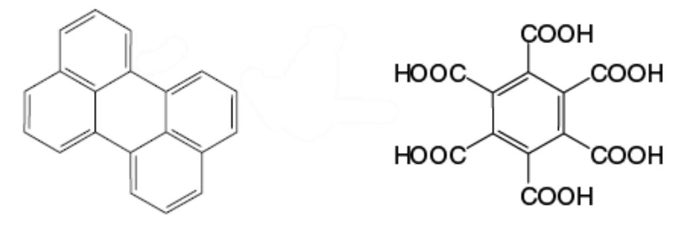


Figure 2. Aromatic biochar-C

Figure 3a.

Autothermic transportable torrefaction machine developed by NCSU forestry PhD student, Chris Hopkins, and poultry science staff Preston Burnette.

Figure 3b.

Biomass torrefaction unit, Dr. Mike Boyette, Biological & Ag. Engineering

Why Biochar?

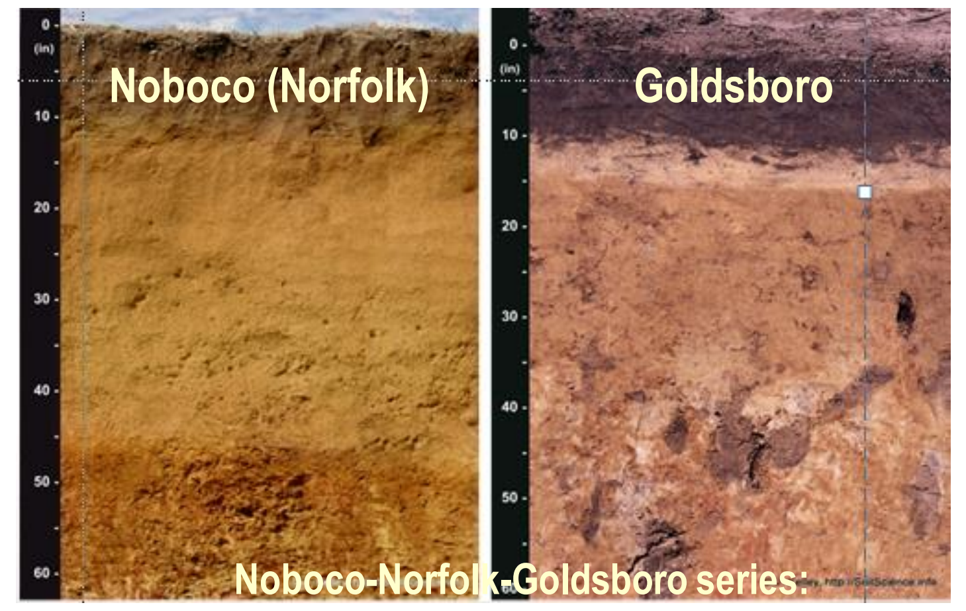
Research in the southeastern U.S. Coastal Plain and elsewhere has indicated that biochar, when added to soil, may:

- slow nutrient leaching
- increase nutrient availability
- decrease fertilizer requirements
- improve N uptake
- reduce soil strength
- Improve water relations
- stimulate beneficial fungi
- sequester C over long time periods

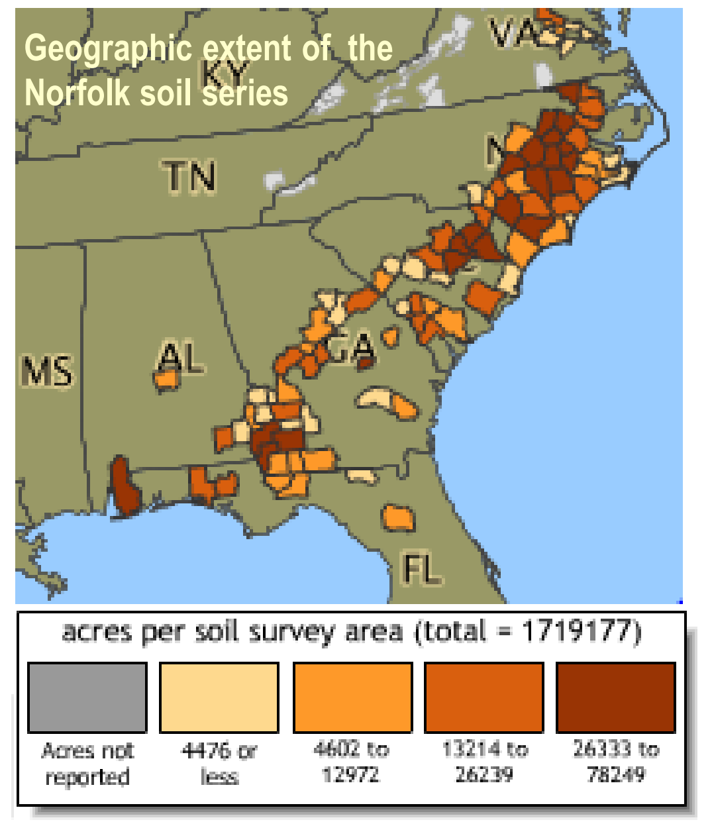
Research Methods

- **Objective**: Evaluate soil and crop response to biochar application in a lower coastal plain mixed Noboco-Goldsboro sandy loam (fine-loamy, siliceous, subactive, thermic Oxyaquic Paleudults: see **Figure 4**) at the Williamsdale Biofuels Research and Extension Center, Wallace, NC.
- **Design and Arrangement**: Five rates of biochar 0, 10, 20, 40, 80 t ha^{-1} with and without N-P-K fertilizer (147-34-34 kg N-P-K ha^{-1}) in a 5 X 2 factorial arrangement with six replications. Locally sourced hardwood chips were used as the biochar feedstock. After decomposition in a closed chamber torrefier, the chips were ground to pass a 5-mm sieve. Biochar was mixed in the surface 15 cm of 1 x 1 m^2 plots after conventional tillage.
- **Cropping System**: A common coastal plain 2-yr rotation (corn [*Zea mays* L.]–winter wheat [*Triticum aestivum* L.]–double-crop soybean [*Glycine max* L. {Merri.}]) was established in the mircroplots: corn (DeKalb 6169 RR) at 60,000 seeds ha^{-1} on 0.76-m rows in June 2008, wheat (Pioneer 26R12) at 66 seeds m^{-1} in Oct 2008 and soybean at 10 seeds m^{-1} in June 2009. A second corn-wheat-soybean-corn iteration was established in spring 2010, terminating in fall 2012.
- **Sampling and Lab Analysis**: One undisturbed soil sample was collected in January 2010 from the surface 0.76 m in all plots in a steel cylinder 0.76 m diameter x 0.76 m high using a Uhland hammer and drive head assembly. Water release was measured by saturating and desorbing the cores in a pressure outflow system at -10, -50, -100, -200, -300, -400, -500 hPa. After oven-drying, soil was ground to pass a 2-mm sieve, re-saturated, and desorbed at -1,000, -5,000, and -15,000 hPa in a pressure plate apparatus.
- **Data and Evaluation:** We computed total, macro-, and matrix porosity; volumetric water content and relative field capacity at -50, -100, -330 hPa tension head; permanent wilting point, total and structural plant available water capacity; soil water retention (SWR) data were fit to the van Genuchten (1980) function via SAS NLIN Leavenberg-Marquardt algorithm; analysis of variance in the Mixed procedure in SAS; mean separation via Tukey's HSD, α = 0.05.

Figure 4.



- Common NC Coastal Plain soils
- Sandy loam and loamy sand texture
- low native fertility-water storage capacity
- Low CEC, ~6 cmol/kg soil
- Subject to compaction and tillage pans



Results

- Biochar ≥ 40 t ha^{-1} increased total porosity, but no differences were detected for macro- and matrix porosity (**Figure 5**.).
- Biochar ≥ 40 t ha^{-1} increased soil water content (Θ_V) at -50 and -100 hPa compared with zero biochar (**Figure 6**).
- 80 t ha^{-1} biochar increased total PAW, and PAW in the -50 to -1,000 hPa structural pore domain (59-3μm equivalent diameter) compared with zero biochar (**Figure 7**).
- Biochar did not improve the relative field capacity (**Figure 8.).**
- Biochar ≥40 t ha^{-1} increased water content at the permanent wilting point (**Figure 9).**
- Biochar decreased soil bulk density greater than that predicted by 'dilution' alone (**Figure 10**); *we hypothesize that increases in structural porosity from biochar were the principal reason for the apparent decrease in bulk density.*
- Soil macropores (>59μm) and matrix pores (<3μm) were unaffected by biochar treatment (from **Figure 5**); *we conclude the apparent increase in total soil porosity in Figure 5 came principally from increases in the structural pore domain*. See **Figures 11a,b.**
- A marginally significant (p=0.03) fertilizer effect was apparent for $\Theta_{V(h=-50\ hPa)}$; fertilizer decreased $\Theta_{V(h=-50\ hPa)}$ by 4% (data not shown); other physical properties were unaffected by fertilizer or B X F interaction (data not shown).

Direct seeding wheat in biochar, June 2011.

Frame resituated after direct seeding wheat

2009: soybean

2009: soybean

Strip-block planted wheat in biochar, June 2011.

Each block has ten 1 x 1 m^2 biochar frames (see arrow). Frames were lifted temporarily to permit drill planting wheat and soybean.

0 t ha^{-1}

20 t ha^{-1}

40 t ha^{-1}

80 t ha^{-1}

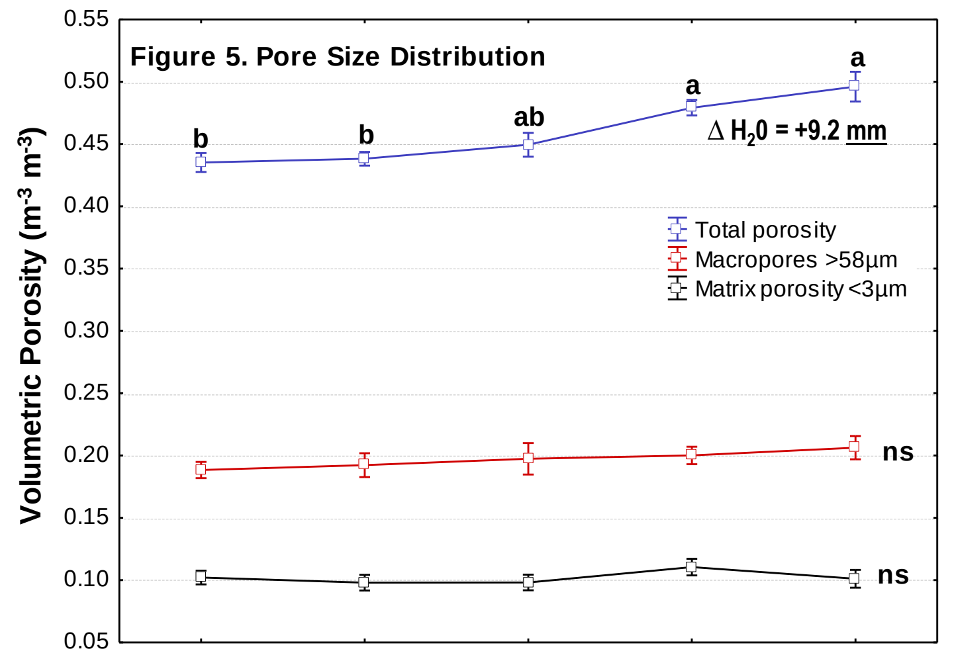


Figure 5. Pore Size Distribution

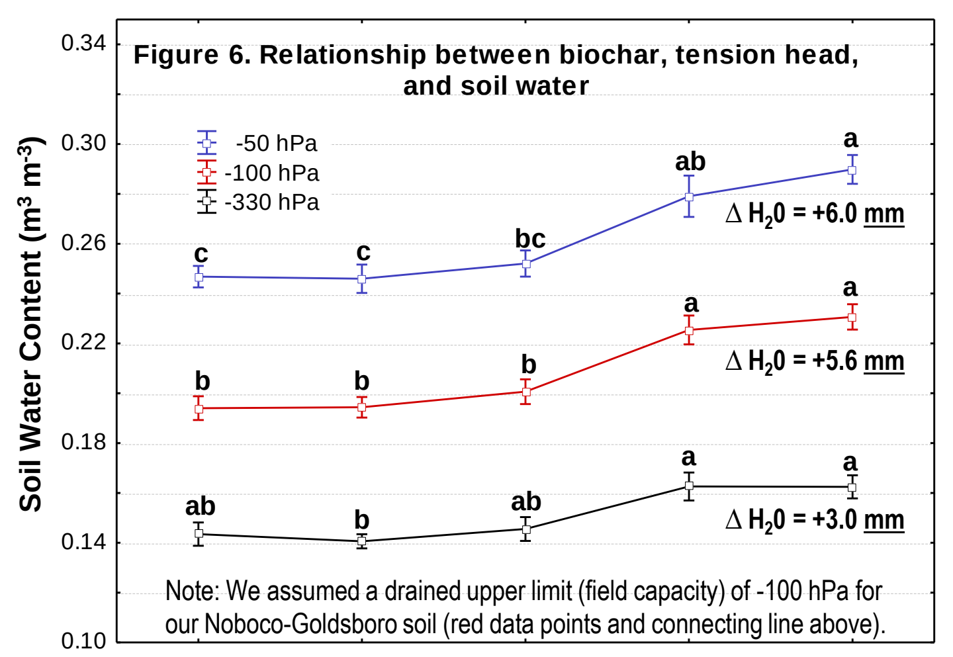


Figure 6. Relationship between biochar, tension head, and soil water

Note: We assumed a drained upper limit (field capacity) of -100 hPa for our Noboco-Goldsboro soil (red data points and connecting line above).

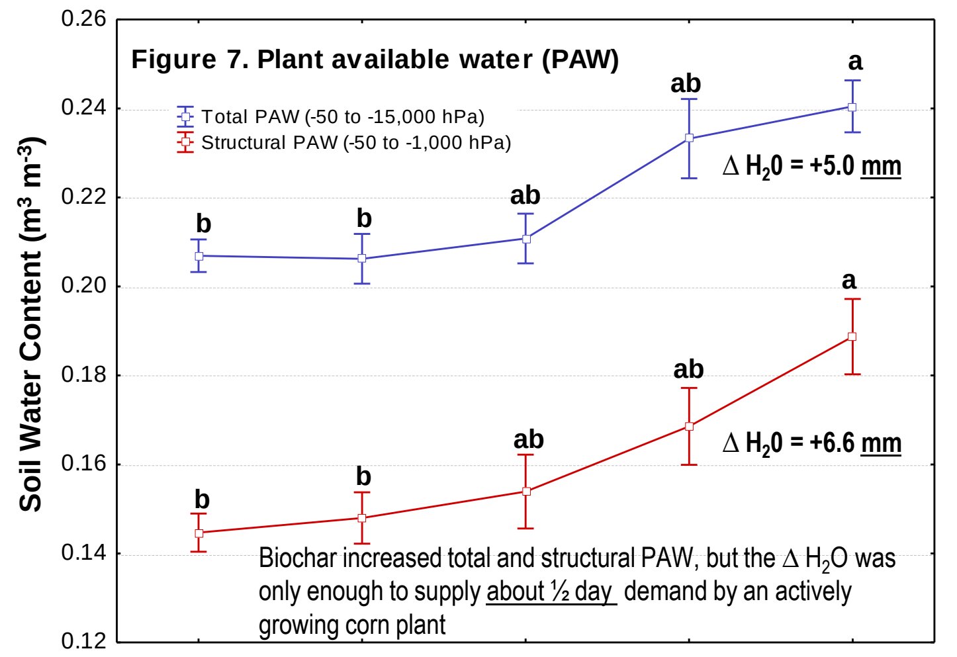


Figure 7. Plant available water (PAW)

Biochar increased total and structural PAW, but the Δ H_2O was only enough to supply about ½ day demand by an actively growing corn plant

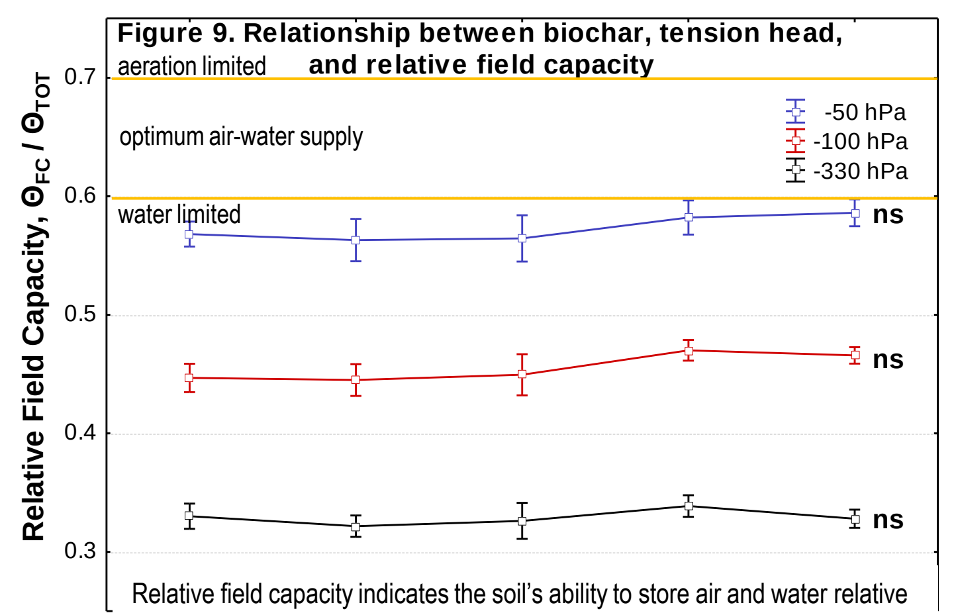


Figure 9. Relationship between biochar, tension head, and relative field capacity

Relative field capacity indicates the soil's ability to store air and water relative to its total porosity. Biochar did not affect RFC. Biochar's ability to improve generally water limiting properties in a Noboco-Goldsboro soil were slight (see orange RFC lines above).

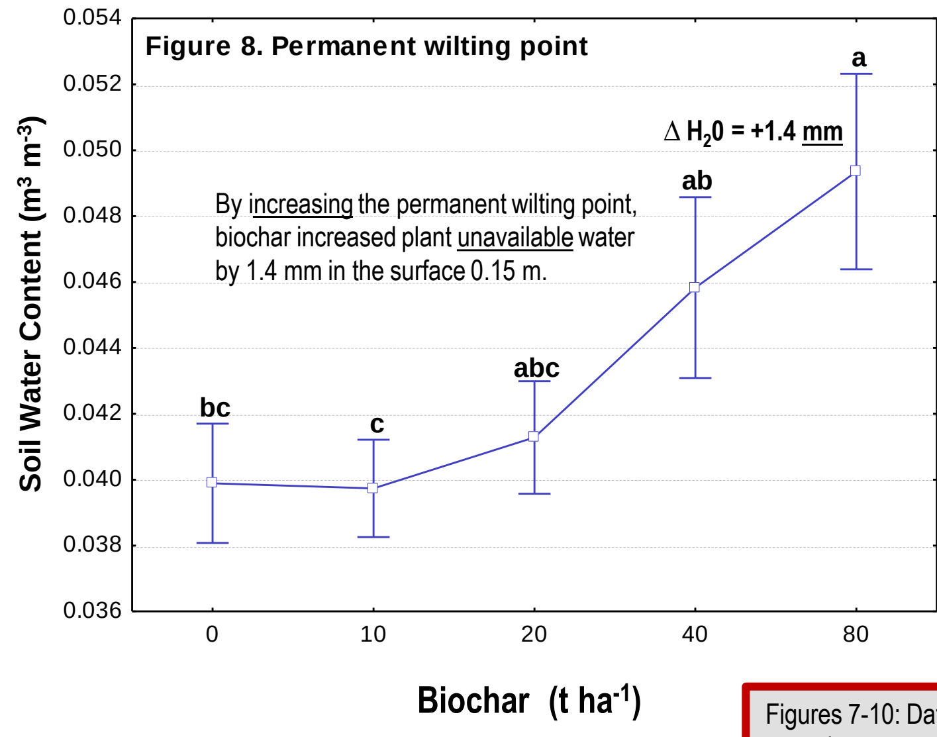


Figure 8. Permanent wilting point

By increasing the permanent wilting point, biochar increased plant unavailable water by 1.4 mm in the surface 0.15 m.

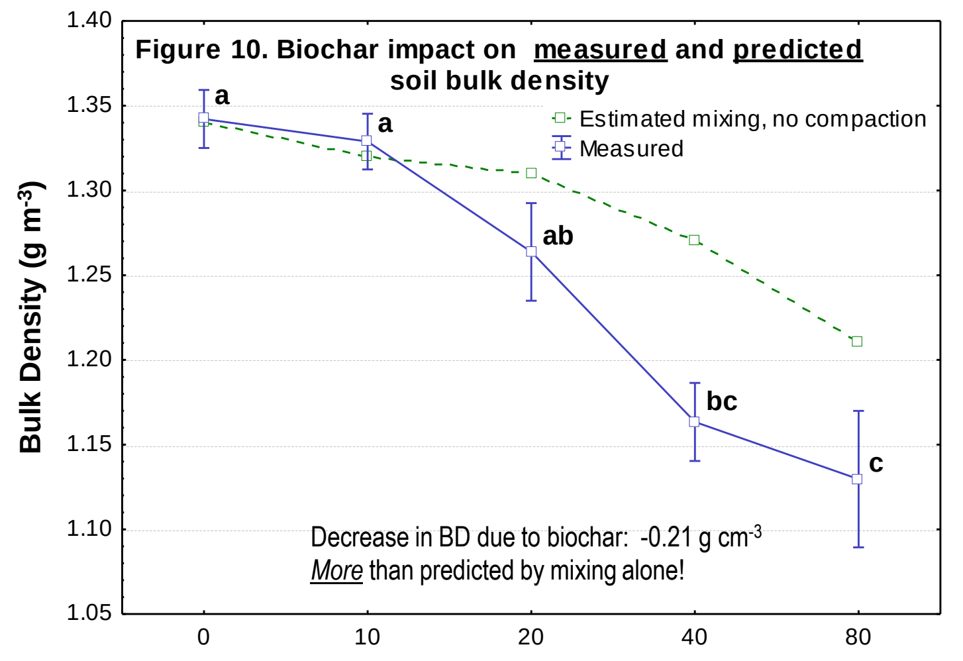
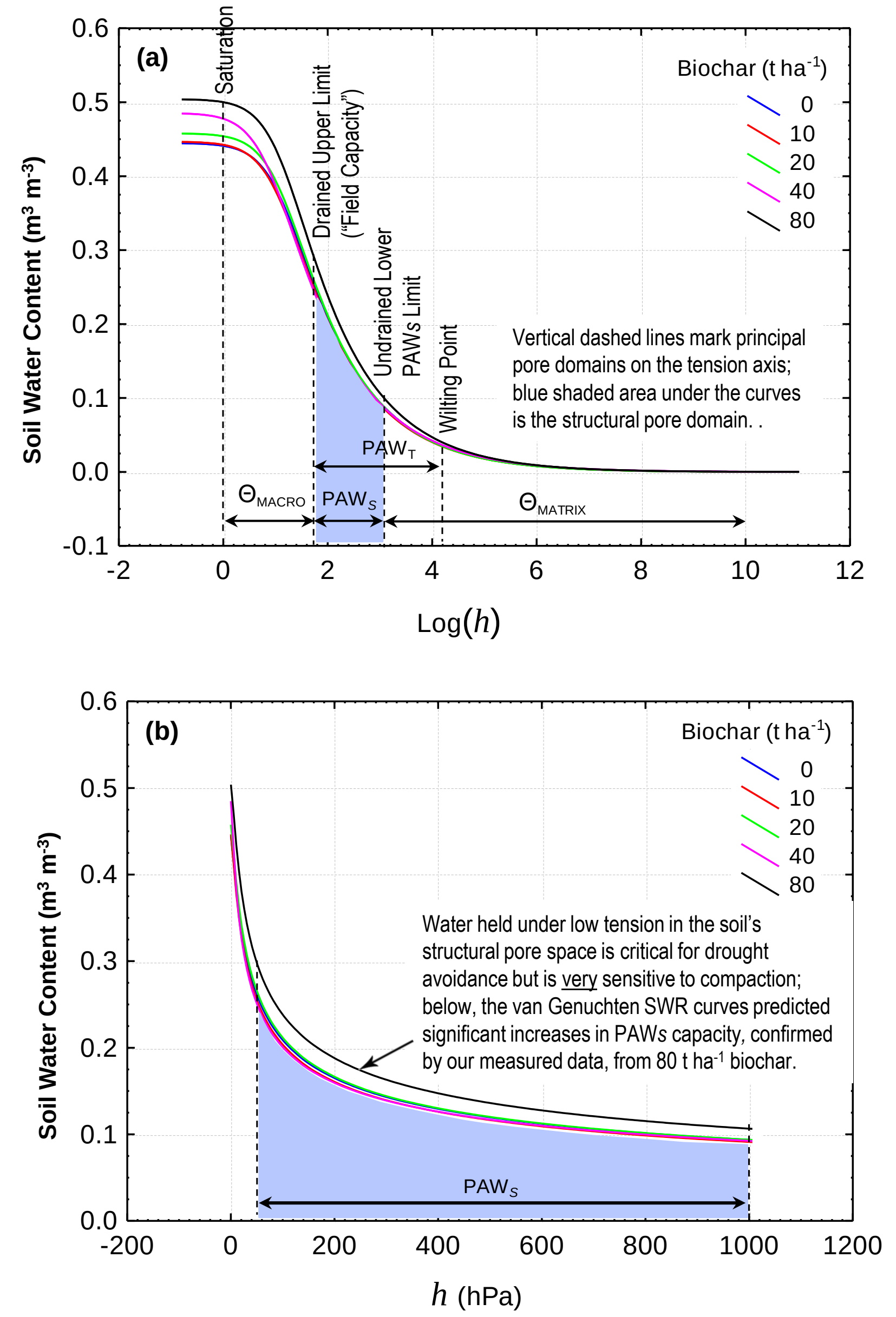


Figure 10. Biochar impact on measured and predicted soil bulk density

Decrease in BD due to biochar: -0.21 g cm^{-3}
More than predicted by mixing alone!

Figures 7-10: Data points represent the mean ±1 standard error pooled over NPK fertilizer (*n*=12). Means with the same letter are not different (α=0.05) under Tukey-Kramer HSD criteria. Δ H_20 represents the difference in depth of water (mm) in the surface 0.15 m between zero and 80 t ha^{-1} biochar.

Figures 11a,b. Biochar SWR data fitted to van Genuchten (1980) function



Vertical dashed lines mark principal pore domains on the tension axis; blue shaded area under the curves is the structural pore domain. .

Water held under low tension in the soil's structural pore space is critical for drought avoidance but is very sensitive to compaction; below, the van Genuchten SWR curves predicted significant increases in PAWs capacity, confirmed by our measured data, from 80 t ha^{-1} biochar.

Interpretive Summary

- Biochar ≥40 t ha^{-1} improved several agronomically important physical properties in a Noboco-Goldsboro sandy loam soil: total porosity, total and structural PAW capacity, low tension (50-330 hPa) water capacity, and bulk density.
- Biochar did not affect macro- or matrix porosity.
- Biochar increased plant unavailable water by increasing the permanent wilting point.
- 80 t ha^{-1} biochar increased PAW in the surface 0.15 m enough to satisfy about ½ day consumptive use by corn at tasseling.
- Biochar had no positive effect on corn, wheat, soybean growth (data not shown).
- Fertilizer had little or no effect on pore size distribution or physical properties.

Future Biochar Research

- Effects on non-agricultural or unmanaged soil?
- Effects on finer-textured NC Piedmont soils?
- Persistence of biochar C for sequestration?
- Large scale field trials?

North Carolina Small Grain Growers Association **Thank you!**