Biochar Addition to a Southeastern USA Coastal Sand to Decrease Soil Strength and Improve Soil Quality

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Abstract: Southeastern USA coastal plain soils are sandy, compacted, and exposed to a subtropical environment; they are low in organic carbon and have little aggregation. In the past, increasing organic carbon to decrease compaction and improve aggregation has been ineffective because organic matter vanishes within a few months in the warm, wet environment. However, organic carbon in the form of charcoal or biochar is recalcitrant having remained in tropical Amazonian soils for centuries. In a lab experiment, we added non-activated biochar to the Ap horizon of a Norfolk loamy sand, a coastal sandy Acrisol. The Biochar was produced in a retort at 700 degrees C and added to soil at rates of 0, 0.5, 1, and 2% (w/w). Switchgrass (*Panicum virgatum*) was also added at rates of 0 and 1% (w/w). Switchgrass and biochar amendments did not show any consistently significant improvements for aggregation or water holding capacities. Soils treated with both amendments had higher infiltration rates than those without amendments. Soil cone indices as a measure of compaction were lower for the higher level of biochar added; biochar showed a relationship of decreasing soil strength with increasing biochar content. Biochar also increased soil carbon contents. Though the biochar did not improve all soil properties, it sequestered carbon and reduced soil strength, two of the more difficult problems to ameliorate in coastal plain soils.
Key words: biochar, switchgrass, cone index, compacted soil, Gracenet

INTRODUCTION

Organic matter (OM) can improve soil tilth and reduce strength. In the southeastern USA, OM oxidizes in the subtropical environment (Parton et al., 1987; Wang et al., 2000). OM increased more for non-inversion tillage systems that maintained crop residue on the surface than for tillage systems that mixed it into the profile; but, the increase for the non-inversion systems was only in the top few centimeters (Novak et al., 2007).

Because OM does not soften the soil especially for subsurface compacted layers, producers annually deep till these sandy coastal soils. Non-inversion deep tillage loosens the soil to allow root growth into deeper horizons where soil structure permits root development and water retention (Akinci et al., 2004). However, deep tillage becomes prohibitively expensive because it requires 20 to 25 liters of fuel ha^{-1} (Karlen et al., 1991) and its effect is temporary. Over time, subsurface horizons reconsolidate (Raper et al., 2000) and that can reduce crop yields.

If OM or carbon could remain in the soils, they might not need annual deep tillage. Organic carbon could improve physical properties, chemical properties, and sequester carbon (Busscher et al., 2007). Biochar or charcoal is a carbon source that might sequester C in the soil and improve its chemical and physical properties. Charcoal is recalcitrant (Steiner et al., 2007) having remained in tropical Amazonian soils for centuries (Mann, 2005). Our hypothesis was that increasing soil carbon through the use of non-activated biochar would improve soil physical properties.

MATERIALS AND METHODS

Pecan (Carya illinoinensis) shells were ground to pass through a 2-mm sieve. Ground shells were poured in a crucible that was placed into a Lindberg box programmable furnace equipped with an air-tight retort that was purged with N2. Pecan shells were heated to 40°C, ramped up to 170°C at a rate of 5°C min-1 and maintained them at 170°C for 30 min. Temperature was increased to 700° C at a rate of 5°C min-1 and held there for 1 hr, producing the biochar. After cooling, the biochar was ground to pass through a 0.6-mm sieve. The pH of the biochar was 7.49; its ash content was 3.8%. The biochar had 88% C, 0.4% N (C:N ratio 220:1).

Soil used in the experiment was the Ap horizon of a Norfolk loamy sand, an Acrisol in the FAO classification. It was collected from a the edge of a 2-ha soybean (Glycine max) research plot 2 km northwest of Florence, SC, USA. The soil was pushed through a 10-mm sieve to remove debris. It was air dried and then passed through a 2-mm sieve.

Norfolk loamy sand formed in marine sediments; it had 1.2- to 1.8-m-deep seasonally high water tables. Over the years, the Ap horizon had been tilled to a depth of about 0.20 m. Below the plow layer, the soil had an eluviated E horizon that restricted root growth. The E horizon typically extended to depths of 0.30 to 0.45 m; it overlaid a sandy clay loam Bt horizon that extended beyond 0.6-m depth. The Ap horizon had 1-3 cmol kg-1 cation exchange capacity, 20 to 80 g kg-1 clay, and 2 to 20 g kg-1 organic matter (Soil Survey Staff, 2008). Soil texture of the Ap horizon was 71.2% sand, 26.5% silt, 2.4% clay.

We developed a control and 7 treatments that consisted of 750 g of soil mixed with all combinations of 0 g kg-1 and 10 g kg-1 switchgrass that had been ground to a fine (>6 mm) powder and 0 g kg-1, 5 g kg-1, 10 g kg-1,and 20 g kg-1 pecan-shell biochar. Treatments were replicated three times.

Soils were packed at 1.2 g cm-3 bulk densities into 10-cm diameter, 17-cm tall PVC columns. It was held in the columns with 20-mesh nylon screens. Before packing, soil was mixed with water in a twin shell dry blender to obtain a moisture content of 10% (w w-1) representing field capacity. Soil was hand mixed with biochar and switchgrass to obtain the treatments. Treated soil was poured into columns as they were then tapped on a lab bench to obtain the desired bulk density which created a free space of 8 to 10 cm above the soil surface. Treatments were maintained at 10% soil water contents on a dry weight basis by weighing and adding water to the columns 2 to 3 times a week. Treatments were incubated in the laboratory for 70 days at room temperature.

At 28 and 70 days, pots were leached with 450 ml of de-ionized water. Then, pots were drained, covered, and allowed to come to equilibrium after which penetration resistance (PR) measurements were taken to determine soil strength. PR was measured at 44 and 96 days on the soil surface with a 3-mm-diameter, stainless-steel flat-tipped probe. The probe was attached to a strain gauge and a motor geared to penetrate the soil at a rate of 0.28 mm s-1 to a depth of 5 mm. Three probings were taken on the soil surface half way from the center to the edge of the pot at equally spaced positions around the circumference; data for these three probings were averaged and treated as a single data point using the method of Busscher et al. (2000).

After the final probe resistance readings were taken, 100-g soil sub samples were taken for aggregate analysis. Aggregate sizes were measured by sieving soil through a 4 mm screen; placing it into a nest of sieves with openings 2 mm, 1 mm, 0.5 mm and 0.25 mm; and shaking the nest at 60 Hz with amplitude of ~3 mm for 1 minute.

Data were analyzed using analysis of variance (ANOVA) and least significant difference mean separation procedure (SAS Institute Inc., 2000). Data were tested for significant differences at $P < 0.05$ unless stated otherwise.

RESEARCH RESULTS

Penetration resistances were measured at 10% water content. After averaging over replicates, water contents for the two days of penetration-resistance measurements ranged from 0.09 to 0.10 g/g with no significant differences among treatments or between days of measurement.

When penetration resistances were analyzed in the ANOVA, treatments with switchgrass added were lower than those without switchgrass for the second date of readings at 0.97 MPa vs. 1.10 MPa (LSD (0.05) = 0.13). It has been known for a long time that the addition of fresh organic matter reduces soil strength. Unfortunately, fresh organic matter does not remain very long in these soils.

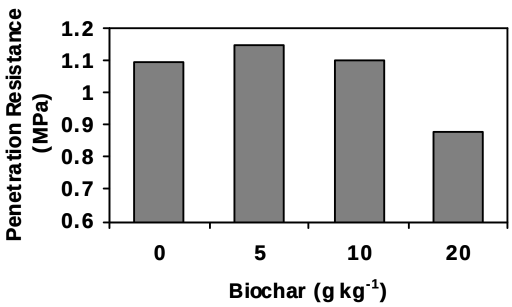

Figure 1. Penetrometer resistance as a function of biochar added, averaged over switchgrass treatments.

When penetration resistances were analyzed in the ANOVA, only the highest biochar treatment had significantly lower penetration resistances than the control. When penetration resistances were regressed against amount of biochar added, they had coefficients of determination of 0.78 taken at 44 days and 0.83 at 96 days, 26 days after the end of the incubation when equilibrium had been reestablished after the final leaching (Fig. 1); these regressions showed a decrease of soil strength with an increase in biochar.

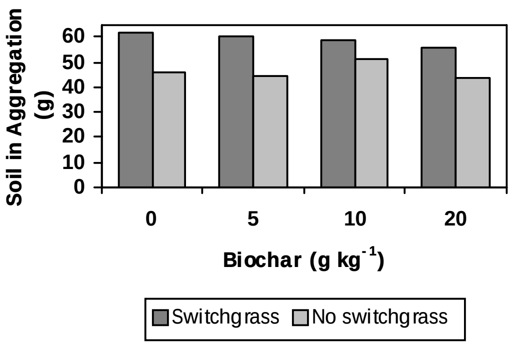

Figure 2. Amount of soil in aggregation for biochar and switchgrass soil amendments.

Biochar and switchgrass amendments did not consistently improve aggregation, infiltration, or water holding capacities. Switchgrass amendments had increased aggregation over treatments without it (Fig. 2); but the difference was not significant. Infiltration for the treatment with no amendment was lower (Fig. 3) than for all the amended treatments.

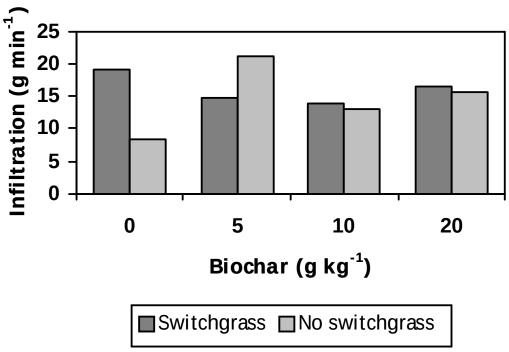

Figure 3. Amount of infiltration as a function of soil amendment.

Water holding capacity was calculated from the water that was added to maintain 10% water content. Water added had no consistently significant differences among the biochar treatments, although the ability to hold water may differ for other types of biochar. The amount of water added to maintain 10% soil water content was lower for some treatments that had switchgrass (Fig. 4). This would be consistent with the fact that soils with more organic matter hold more water, though the difference was not consistent across all levels of biochar additions.

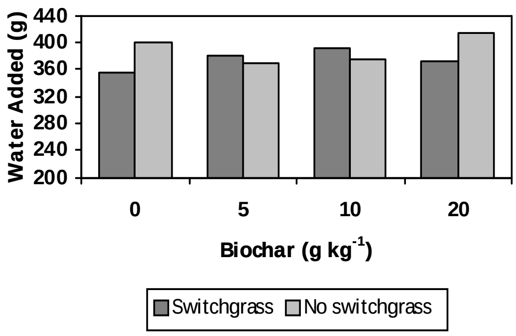

Figure 4. Water added to various treatments to maintain 10% water content on a weight basis.

Conclusions

Adding switchgrass improved soil penetration resistance and some soil water holding capacities. It also improved aggregation and infiltration but improvement was not significantly different. Switchgrass additions will be short lived because fresh organic matter deteriorates quickly in this climate.

Adding biochar only improved soil penetration resistance. Other biochars might affect the soil differently. Decreasing penetration resistance and increasing recalcitrant C should benefit these coastal soils that characteristically have high penetration resistances and low C.

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