SOIL AMENDMENTS TO DECREASE HIGH STRENGTH IN SE COASTAL PLAIN HARDPANS

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ABSTRACT

Southeastern Coastal Plain loamy sands often contain cemented subsurface hard layers that restrict root development. Soil properties are usually improved by tillage but can also be improved by adding soil amendments. Wheat and polyacrylamide (PAM) amendments were mixed into a Norfolk soil, a mix of 90% hard layer soil and 10% Ap horizon to assure microbial activity. Our hypothesis was that incorporation of wheat and PAM would improve soil physical properties, making the soil more amenable to root growth. Treatments contained 1 lb of soil, 6.44 lbs lb^{-1} wheat stubble, and 30 or 120 PPM of PAM; duplicate sets of treatments were incubated for 30 d and 60 d at 10 % (w/w) water content. Treatments were leached with 1.3 pore volumes of water. After leaching and equilibration to stable water contents, soil strengths were measured with a .12-in diameter flat-tipped bench-top penetrometer. PAM formulation of 2.64×10^4 lbs $mole^{-1}$ molecules, anionic, and 35% charge density decreased bulk density when added at the higher rate of 120 PPM of soil. The higher PAM rate also decreased the amount of water that was needed to maintain treatments at 10 %. Both PAM and wheat amendments decreased penetrometer resistances and increased aggregation. Amendments improved soil physical properties, especially when the higher rate of PAM was used and when treatments were allowed to incubate for a longer period of time.

INTRODUCTION

In many southeastern Coastal soils, high strengths can develop in subsurface E horizons. Strengths can reduce or prevent root growth (Blanchar et al., 1978). Typically, strengths are managed by disrupting the E horizon with non-inversion deep tillage that increases root growth and yield (Raper et al., 2000). Unfortunately, over time, tillage effects diminish and yields again decrease as soil strength rebuilds (Arvidsson et al., 2001). In some cases, strength rebuilds over the period of a few years (Munkholm et al., 2001); in other cases, it rebuilds in only one or two seasons (Frederick et al., 1998); and the cycle begins again. As a result, producers in the southeast deep till annually.

Deep tillage costs \$15 to \$25 a^{-1} (Khalilian et al., 2002), plus increases due to high fuel costs. Tillage can be reduced and costs lowered by adding soil amendments such as soil organic matter and PAM. It has been known for a long time that organic matter additions will improve soil tilth (Waksman, 1937) and reduce strength (Free et al., 1947), even for soils such as those found in the Coastal Plain (Ekwue and Stone, 1995). However, organic matter oxidizes rapidly because of high summer temperatures (Wang et al., 2000) and it does not increase over time or it increases only near the surface (Novak et al., 1996).

Another amendment that can reduce deep tillage is polyacrylamide (PAM). It can reduce tillage by increasing soil aggregation which would disrupt the massive structure that causes the hard layer. PAM addition has the added benefit of helping retain organic matter (OM) in the soil by incorporating it into aggregates where it can be protected from decomposition (Goebel et al., 2005; John et al., 2005). In the early 1950's, older PAM formulations were used as soil conditioners (Weeks and Colter, 1952). PAM and other conditioners were found to improve plant growth by reducing soil physical problems, stabilizing aggregates in the surface 12- to 16-in depths. Unfortunately, the older formulations required hundreds of pounds of PAM per acre with multiple spraying and tillage operations. Newer polymer formulations and purity have improved PAMs, making them more effective at lower concentrations. Water soluble PAM was identified as a highly effective erosion-preventing and infiltration-enhancing polymer, when applied at rates of 10 PPM in furrow irrigation water (Sojka and Lentz, 1997; Sojka et al., 1998a; Trout et al., 1995). PAM achieved this result by stabilizing soil surface structure and pore continuity. Since the effect was limited to the surface few millimeters of soil, efficacy was achieved at application rates of 1-2 lbs a^{-1} per irrigation.

We hypothesized that adding low concentrations of a newer PAM formulation to sandy coastal soils could decrease soil strength and bulk density and increase aggregation.

MATERIALS AND METHODS

Soil type

The soil used in the experiment was a mix of 90% of the E horizon and 10% of the Ap horizon (to assure microbial activity) of a Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudult). It was collected from a field 1 mile northwest of Florence, SC and poured through a 0.4-in sieve to remove debris. Norfolk soil formed in coastal marine sediments and had a seasonally high water table at 48- to 72-in depth. Over the years, the soil developed an Ap horizon by being tilled to a depth of about 8 in. Below the plow layer, the soil had an eluviated E horizon that restricted root growth (http://soils.usda.gov/technical/classification/osd/index.html, accessed February 2006). The E horizon extended to a depth of 12 to 18 in overlaying sandy clay loam Bt horizon that extended beyond 24-in depth.

Treatments

Six treatments included all combinations of soil mixed with 2 organic matter levels and three PAM levels. Organic matter treatment levels were 0 and 6.44 lbs lb^{-1} ground wheat stubble. Organic matter and soil C:N ratios were brought to 20:1 by adding nitrogen in the form of NH_4NO_3 in amounts of 0.157 lbs lb^{-1} and 0.456 lbs lb^{-1} for the treatments with no wheat and wheat stubble, respectively. PAM treatment levels were 0 PPM, 30 PPM, and 120 PPM. The PAM formulation was 2.64×10^4 lbs $mole^{-1}$ molecules, anionic, and 35% charge density[1] (SNF Inc, Riceboro, GA, USA). Each treatment was replicated three times.

Because the amount of PAM added to the soil was so small and it did not mix well in the dry state, the various treatments were dissolved into 1.5 oz of deionized water and sprayed onto the

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[1]Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agriculture and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

soil or soil and ground wheat straw while mixing it on waxed paper. Treatments were based on the dry weight of 1 lb of soil which was packed into 4-in diameter pots with a 20 mesh nylon screen on the bottom to prevent soil from leaking out drain holes. Treatments were packed to a bulk density of 75 lbs ft^{-3} by pouring amended soil into the pots and tapping them on the lab bench until the soil settled to a preset line.

Duplicate sets of treatments were incubated for periods of either 30 or 60 days in a lab that was maintained at 68 to 70 degrees F and ambient humidity. Treatments were maintained at 10 % soil water content on a dry weight basis by weighing and adding water to the pots 2 to 3 times a week.

Measurements

At 28 and 56 days after the beginning of the experiment, pots were leached with 1.3 pore volumes of water. After leaching, pots were drained, covered, and allowed to come to equilibrium before penetrometer resistance (PR) readings were taken to determine soil strength. At 42 and 73 days, penetration resistance was measured on the soil surface with a 0.12-in-diameter, stainless-steel flat-tipped probe. The probe was attached to a strain gauge and a motor geared to penetrate the soil at a constant rate of 0.01 in s^{-1}. Strain gauge output was expressed in millivolts and read at a rate of 100 hz on a CT-23X Micrologger (Campbell Scientific, Inc, Logan, UT, USA) while the probe penetrated the top 0.2 in of the core. Output was uploaded to a desktop computer. After probing to 0.12- to 0.16-in depth, output either reached a plateau or peaked and receded. In either case, the mean of the top ten values was used as the reading for each probing. 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 the three probings were averaged and treated as a single data point. Data were converted from millivoltage to penetration resistance using a previously-developed calibration PR = f(V) with $r^2 = 0.99$ where PR is probe resistance and V is voltage (Busscher et al., 2000).

At 14, 24, and 53 days, soil bulk densities were calculated from averages of the distance from the top of the pot to the soil surface at three points along the side of the pot and one point in the center of the pot. To determine the volume of soil in a pot, distances along the side of the pot were calibrated against volume of the pot by sealing the drain holes at the bottom and filling the pot with water to several depths, giving a linear relationship Vo = f(d) with $r^2 = 0.99$ where Vo is volume of the pot filled with water and d is depth of water in the pot. Volumes were combined with known dry weights of each treatment to calculate bulk densities.

At the end of each treatment's incubation period, 30 d or 60 d, aggregate sizes were measured by pushing 0.15 lb of soil through a 0.16-in sieve and placing it into a nest of sieves with openings 0.08 in, 0.04 in, 0.02 in and 0.01 in and shaking the nest with an Octagon Digital Sieve Shaker (Endecotts, Inc., London) using the procedure of Sainju et al. (2003).

Data analysis

Data were analyzed using analysis of variance and Fisher's protected least significant difference mean separation procedure (SAS Institute Inc., 2000). When data were taken over several dates, readings at specific dates were considered main plots with treatments as splits in a split plot design. When readings for the two sets of treatments were considered together, the sets were considered main plots with treatments within sets as splits. Data were tested for significant differences at the 0.05 level.

RESULTS AND DISCUSSION

Bulk density

Bulk densities did not vary between wheat and non-wheat treatments but they did vary with PAM treatment and time of measurement. Bulk densities were lower for the 120-PPM PAM treatments at 84.3 lbs ft^{-3} than for the treatments with no PAM at 85.5 lbs ft^{-3} or the treatments with 30-PPM at 86.2 lbs ft^{-3} (LSD at 5 % = 0.62). The decreased bulk densities were probably caused by the aggregating action of the PAM as seen by Levy and Miller (1999). Bulk densities increased with time (Fig. 1), starting at a packed value of 75 lbs ft^{-3} and increasing to 87 lbs ft^{-3} by the end of the experiment which would be associated with an increase in soil strength (Chan and Sivapragasam, 1996) probably as a result of settling.

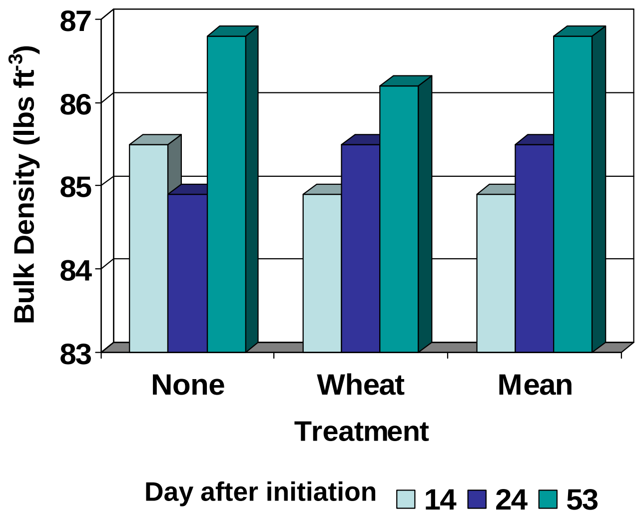

Figure 1. Bulk densities (lbs ft-3) for treatments on 14, 24, and 53 days after beginning of the experiment.

Penetrometer resistance

Penetrometer resistances were taken about two weeks after leaching because pots were too wet to give significant readings before those dates. Penetrometer resistances could also be affected by water content readings if they differed among treatments with wetter soils having naturally lower readings. To allow treatments to come to equilibrium, penetrometer resistance readings were taken after about two weeks of drainage where the pots were covered with plastic wrap. For penetrometer resistance reading taken 42 d after initiation of the experiment, water contents differed for both the wheat and PAM treatments with values of 10.8 % for the wheat treated soil and 10.0 % (LSD at 5 % = 0.3 %) for the treatment with no wheat. Water contents increased with PAM content, having values of 9.7 %, 10.5 %, and 11.1 % for treatments

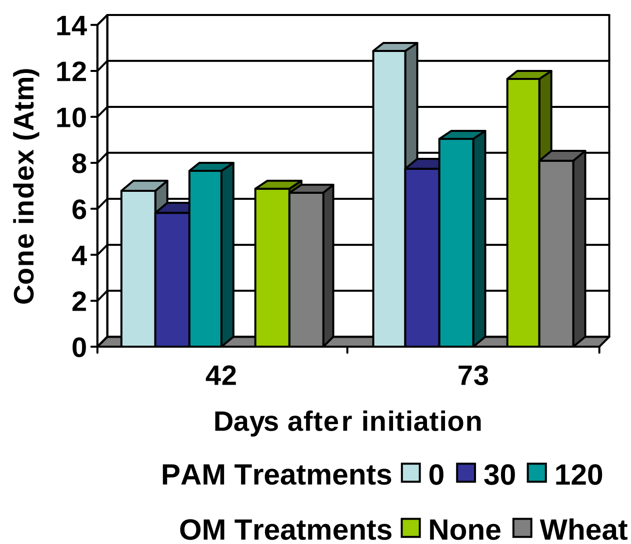

Figure 2. Penetrometer resistances (MPa) for treatments after they were covered and allowed to come to equilibrium for about two weeks.

with 0, 30 mg kg^{-1} and 120 mg kg^{-1} PAM respectively (LSD at 5 % = 0.4 %). For penetrometer resistance readings taken 73 d after initiation of the experiment, water contents were not significantly different among treatments with values ranging from 8.7 to 8.9 %. Water contents would have to be taken into consideration for the first date of penetrometer resistance measurement.

For either measurement date, penetrometer resistance results were the same whether water content was added as a cofactor in the statistical analysis or not, suggesting that the water content differences of 1.1 % or less may not be enough to alter results. Furthermore, regressions of penetrometer resistance with water contents did not reveal any significant relationship, yielding, for example, an r^2 of only 0.01 when the two were related linearly.

For the measurements taken at 42 d, penetrometer resistances were only marginally higher for the treatment without wheat than for the treatment with wheat (Fig. 2). And though they differed for the PAM treatments, there was no trend with amount of PAM. For the measurements taken at 73 d, penetrometer resistances differed among both PAM and wheat treatments; they were both lower than their non-amended counterparts. And though PAM did not show a trend, penetrometer resistances for both treatments were lower than the treatment without PAM. Decreased penetrometer resistances have been related to increased aggregation and PAM amendment by Sojka et al. (1998b). And lower penetrometer resistances for treatments with organic matter added and the associated increase in aggregation have been observed by many researchers (Sanchez et al., 2003; Hamza and Anderson, 2005).

Cumulative water added

The amount of water added to each pot was shown in Fig. 3; it was averaged over the dates when water was added to bring the treatments up to 10 % water content. Water added was analyzed separately for the treatments that ended at 30 d and those that ended at 60 d, though the same results were attained if data for both sets of treatments were analyzed at 30 d. At 30 d, the amount of water added was not significantly different for the wheat treatments and less for the 30 PPM PAM treatment than for the others. At 60 d, less water was added for the treatments with wheat than for the treatments without wheat and less water was added to the treatments with PAM than to those without it. In both cases, treatments with wheat and PAM amendments, less water added implies that PAM and wheat were holding water against evaporation and/or

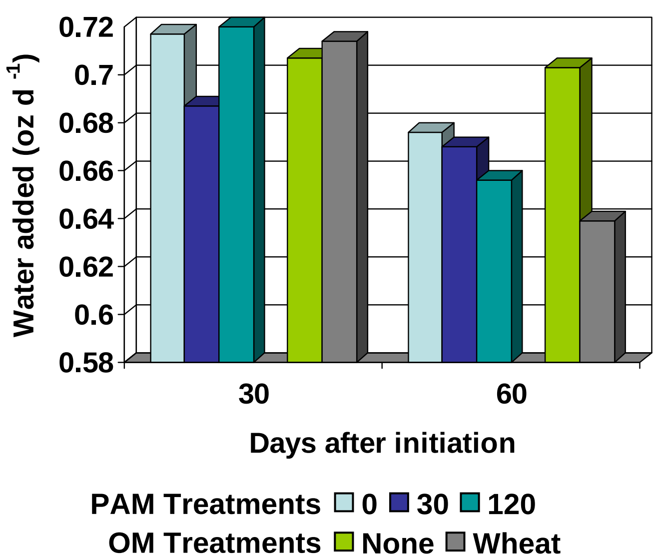

Figure 3. Amount of water added (in oz / g averaged over dates of water addition) throughout the course of the experiment for the treatments that ended on days 30 and 60.

drainage. Though the differences were small, they suggest that the amendments were altering the soil by increasing aggregation, similar to the study of Green et al. (2004) where PAM stabilized aggregation in a crusting/erosion study.

Aggregation

Though aggregates were measured on a nest of sieves, the fractions that remained on the largest sieve and the fraction that fell through the smallest sieve were not analyzed as aggregates but considered respectively as a mix of loose organic matter with aggregates or small aggregates mixed with individual particles. Aggregates analyzed on the other three sieves fell in the size range of 0.08 in to 0.01 in. At 60 d, the smallest size had more aggregates and amounts decreased with increasing size; the smallest size had 5.2 %, next largest 2.3 %, and largest 1.4 % (LSD at 5 % significance = 0.3).

Amount of aggregation increased (Fig. 4) with increasing amounts of PAM as seen by others (Sojka et al., 1998a), though it was only significant for the 120 PPM treatment at 60 d. Treatments amended with wheat had more aggregation than the treatment without it (Krull et al., 2005).

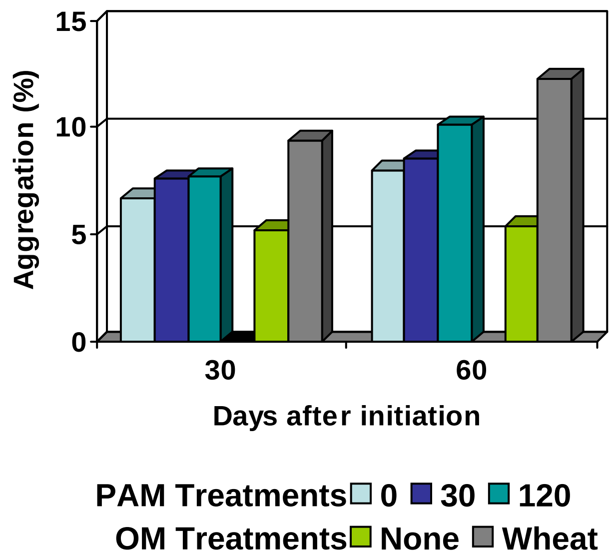

Figure 4. Amount of aggregation (%) developed during the experiment for the treatments that ended on 30 d and 60 d.

CONCLUSIONS

When soils were amended with wheat or with a PAM formulation of 2.64 x 10^4 lbs $mole^{-1}$, anionic, and 35 % charge density at both 30 mg kg^{-1} and 120 mg kg^{-1}, they appeared to have improved aggregation and associated properties. Amended soils needed to have 0.4 to 1.2 oz lb^{-1} less water added to bring them to 10 % indicating that more water was being held in the soil against leaching or evaporation. This suggested that wheat and PAM were increasing aggregation and the aggregates were holding water. When wheat and PAM were added to the soil, penetrometer resistances and bulk densities decreased with amendment which would also be consistent with increased aggregation. Aggregation, as measured by dry sieving, increased when soil was amended with PAM and wheat, though the PAM difference was only significant at the higher amendment level and only at the 60-d measurement.

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