

EFFECT OF VERTICAL TRENCHING OF CELLULOSE WASTE ON CROP YIELD AND HARDPAN RECONSOLIDATION

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ABSTRACT. Trenches placed midway between rows were filled with a mixture of soil, cellulose material, and poultry litter. Soybeans and grain sorghum were grown in rows adjacent to the trenched areas for multiple years. Results showed that a trenching effect, with or without the presence of cellulose, significantly increased plant yields, particularly in dry years. Cone index measurements taken three years after the trenches were created showed no sign of hardpan consolidation from natural forces. **Keywords.** Soil compaction, Cone index, Carbon, Nitrogen.

Soil compaction problems are evident to farmers throughout the United States, but problems are often acute, particularly in the southeastern United States (Cooper et al., 1969; McConnell et al., 1989; Mullins et al., 1992). Here, Coastal Plains soils exhibit layers of extreme compaction from both natural causes and wheel traffic. These compact layers impede root growth and restrict water movement, thereby reducing the plant's capacity to obtain water during drought. These problems are especially severe in the southeastern United States because of the low organic matter content and low water holding capacity of Coastal Plains soils, coupled with frequent short-term drought.

The most common method of alleviating layers of extreme soil compaction is subsoiling (Garner et al., 1984; Reid, 1978; Campbell et al., 1974). This process of moving a tillage tool through the soil requires a large amount of energy. Disruption of soil horizons down to depths of almost 0.7 m are common, but the practice is not a permanent solution. Due to natural reconsolidation and surface forces of random traffic, the soil tends to recompact and requires periodic subsoiling.

One method that has been proposed to lengthen the time between periodic subsoiling is to incorporate some type of non-soil, foreign material into the subsoiled zone to keep the soil particles from cohering to each other and to provide extra pore space for water infiltration and storage. Crop residue was plowed into the soil by Spain and McCune (1956) as a method of alleviating heavy straw

concentrations left on the soil surface after large crop yields. This heavy straw concentration was interfering with planting operations and preventing timely field operations. Curley et al. (1958) investigated burial of organic materials, including hay and corn cobs, as a method of deepening the plant root zone. They found that large increases in crop yield were achieved in the first year of the experiment. Yields were variable in later years, however, due to heavy winter rains which provided adequate moisture to all plots. A Canadian experiment (Clark and Hore, 1965) found that vertical mulching (as it came to be called) had little effect on crop yields or on soil moisture distribution.

Saxton (1980) hypothesized that one reason for the failure of the vertical mulching system developed in the 1950s is that trench surfaces were sealed during subsequent plowing operations. Saxton (1980) proposed a system by which the crop residue was not completely buried but was allowed to protrude above the soil surface and intercept free water. The subsoiled zone would then have a longer lifespan, infiltration would be increased, and the problems associated with surface sealing would be alleviated.

An implement was developed to vertically mulch residue cover in the Pacific Northwest of the United States (Hyde et al., 1986, 1989). Vertical shanks, parabolic shanks, and rotary slot cutting devices were compared to determine the best method of creating a vertical trench for depositing residue cover. It was found that a vertical shank operating to a depth of 26 cm with a 22° lift angle minimized draft requirements and formed the best slot when combined with a pair of preceding coulters that cut to about half the depth of the slot. A machinery system similar to the one developed in the Pacific Northwest was developed to handle corn (*Zea mays* L.) residue Edwards and Rumsey, 1989).

Preliminary studies have been conducted in the Southeastern United States using cotton (*Gossypium hirsutum* L.) as an indicator crop (Edwards et al., 1992a,b, 1995) where trenches were dug and filled with a mixture of soil, cellulose, and poultry litter. Results indicated that cotton yields increased when the waste cellulose material was applied in a vertical trench between plant rows.

A potential benefit of this system is its ability to use virtually any organic material as the non-soil foreign

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substance. Because an abundance of waste cellulose materials are currently available and are filling up valuable landfill space (Rathje, 1991), the potential exists for farmers to offset machinery and energy costs by potential payments from municipalities for disposal of a portion of their solid waste. This would be in addition to any yield increases that farmers might achieve. According to Burt et al. (1992) waste disposal costs for municipal landfills vary from U.S. \$44 to 154/Mg, depending upon location. They reported that if waste could be applied to agricultural soil at a rate of 27 Mg/ha with a 1-m spacing between trenches, landfill costs of U.S. \$1,188 to 4158/ha could be avoided.

Commercialization of this process has not been successful, primarily because yield increases have been insufficient to overcome machinery and tillage energy costs. More experiments are needed in the southeastern portion of the United States where hardpan problems are prevalent to determine potential benefits from this process on various crops. This research requires a substantial amount of labor to place the cellulose materials into the subsoiled zone. For this reason, an implement was needed to create a subsoiled zone and apply waste materials in one pass before additional experiments can be performed.

The objectives of this study were to:

1. Evaluate an implement designed to subsoil and apply waste material in one pass.
2. Determine the effect of waste cellulose material applied in trenches on crop response.
3. Determine the effect of cellulose waste on hardpan reconsolidation in Coastal Plains soils.

METHODS AND MATERIALS

An implement was developed at the USDA-ARS National Soil Dynamics Laboratory (Washington and Burt, 1995) for subsoiling and applying waste cellulose material in one pass (fig. 1). The implement consists of a 15-cm wide shank which is used to subsoil to a 61-cm depth. The sides of the shank are covered in polyurethane to minimize frictional forces from the sides of the subsoiled zone. The sides of the shank also tend to stabilize the subsoiled trench and keep it open so that the deposited cellulose waste material can flow freely to the bottom.

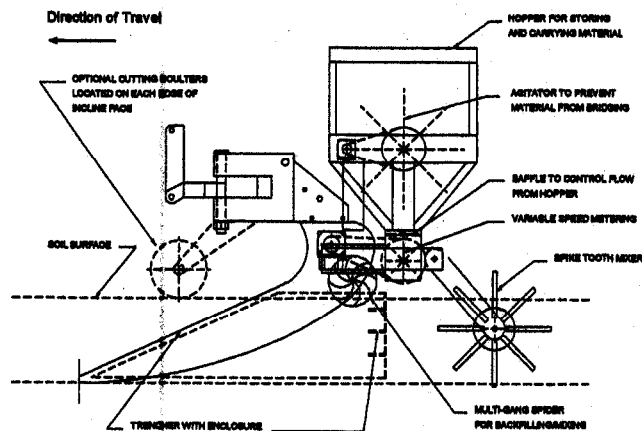


Figure 1-Left-side view of implement to subsoil and deposit waste cellulose material in a narrow trench.

The cellulose-disposal implement includes a large hopper which holds the waste materials to be applied. Flexible fingers mounted inside the hopper and powered by a hydraulic motor rotate and dispense the waste cellulose material directly into the soil behind the subsoiler shank. Soil is then brought back into the subsoiled zone by rotating spider wheels which run to the rear of the shank. A mixing wheel is located at the very rear of the machine to enhance mixing of soil and waste cellulose material. Excavations performed during initial trials showed that a uniform mixture was being obtained along the depth of the trench.

The implement was used in two investigations of vertical mulching at the Alabama Agricultural Experiment Station E.V. Smith Research Center near Shorter, Alabama. Because waste cellulose material had to be manually shredded and varied in consistency, the decision was made to obtain shredded newspaper that is used for insulation (CEL-PAK, Decatur, Ala.). This material was passed through a 9.5mm screen before being packaged into 11.4-kg bundles. Analysis of the shredded newspaper showed it to contain 48% carbon and less than 0.5% nitrogen.

One of the objectives of the experiment was to determine if the application of the cellulose materials affected plant growth. Therefore, obtaining a correct C:N relationship was important and three treatments of this factor were included. The first treatment consisted of applying the cellulose material directly to the subsoiled zone without any modifications. In this treatment, the cellulose material had a C:N ratio of approximately 125:1. The second and third treatments consisted of adjusting the C:N ratio to approximately 25:1 by adding either a urea ammonium nitrate solution (32% N) or poultry litter to the shredded newspaper prior to application. Analysis of the poultry litter a few days prior to the experiment showed it to contain 22% carbon and 3% nitrogen.

An arrangement of rows and trenches provided a plot area which could be used to observe both C:N effects and trench effects. Eight-row plots with a row spacing of 0.76 m were used with trenches placed halfway between rows 2 and 3 and rows 6 and 7 (fig. 2). Each plot was 18.3 m in length with a 6-m buffer zone between plots. The experimental layout consisted of placing a trench with the cellulose material mixture on one side of the plot (between rows 2 and 3) and placing a trench with no cellulose material on the other side of the plot (between rows 6 and 7). The trench between rows 6 and 7 with no cellulose material was constructed with the cellulose disposal implement, but with nothing applied in the trench area. It was assumed that rows 2 and 3 would benefit from the trench with the cellulose material, and rows 6 and 7 would

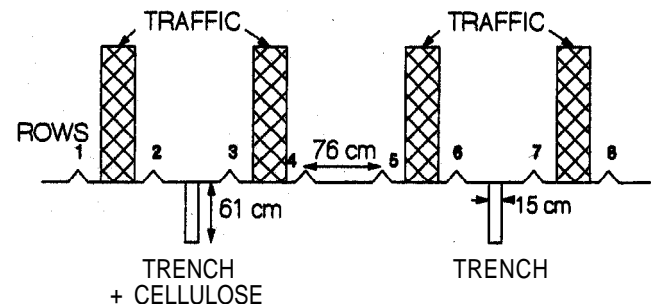


Figure 2-Position of trenches relative to rows and wheel traffic.

benefit from the trench alone. Rows 4 and 5 would receive no trenching benefit and should provide a useful control. Rows 1 and 8 were used as buffer rows.

Each of the two experiments contained four replicates. A Cahaba-Wickham-Bassfield sandy loam soil (fine-loamy, siliceous, thermic *Typic Hapludults*; fine-loamy, mixed, thermic *Typic Hapludults*; coarse-loamy, siliceous, thermic *Typic Hapludults*) with a predominant hardpan which is prone to reconsolidation was used to grow grain sorghum [*Sorghum bicolor* (L.) Moench]. A similar experiment was performed in a Norfolk sandy loam soil (fine-loamy, siliceous, thermic *Typic Kandindults*) with soybeans [*Glycine max* (L.) Merr.]. The soybean experiment received no poultry litter treatment because it was thought that this treatment would be of little benefit because soybeans fix their own nitrogen.

The trenches were formed and the shredded newspaper applications were made in June 1993. Application of fertilizer (based on soil test recommendations) was made to all plots at time of planting. Because very little rain fell, a small amount of water (≈ 2.5 cm) was used to irrigate both sets of plots early in the growing season to prevent loss of crop. At the conclusion of the growing season, the center 9.1 m of each plot along the plot length was harvested for crop yield.

No shallow or deep tillage was conducted on the plots during the period that the experiments were being conducted other than the initial trenching operation which was only performed the first year. The row locations were not moved from year to year because no tillage was performed to disturb old row locations. The only traffic that was allowed in the plots was for planting, spraying herbicide, and harvesting (fig. 2).

The soil condition at the end of each growing season was determined by recording the force required to push a soil cone penetrometer (ASAE, 1993) vertically into the soil at depth increments of approximately every 3 mm. The soil cone penetrometer is an indicator of soil strength and simulates the force that roots encounter when growing in a particular soil condition. The forces recorded are then divided by the cross-sectional base area of the cone to calculate cone index.

Several profiles were taken in the first replication of the sorghum experiment across the plot area both inside the trench and in nearby untrenched areas in October 1993, to assess the effect of trenching on soil condition. A series of 17 measurements were made across plots in the three C:N treatments Raper et al., 1995). A complete set of soil cone penetrometer measurements were taken in March 1996 at 19-cm increments across the 76-cm rows in the soybean plots to determine the resulting soil condition after three consecutive years of crops. At six locations in each plot, penetrometer measurements were taken both in the trench that contained cellulose and in the trench that did not contain cellulose. Measurements were also taken halfway between the trench and the row as well as in adjacent rows.

In each plot in the grain sorghum experiment, two ceramic cup lysimeters with 0.4 micron pore size (Soil Moisture Equipment, Inc., Santa Barbara, Calif.) were installed midway between the plant row and the trench at depths of 0.6 m and 1.2 m (Hill et al., 1995). Water samples were taken monthly in 1993 to determine if any nitrogen leaching could be detected, particularly in the

plots that received the added nitrogen. The limited data available for these months indicated that none of the applied nitrogen in the trenches leached below the 1.2-m depth (Hill et al., 1995). However, the trench that contained only cellulose material and had a C:N ratio of 125:1 caused direct vertical movement of $\text{NO}_3\text{-N}$ to below the rooting depth. This could allow nitrate from fertilizer to become a potential ground water contaminant.

Grain yield data were analyzed for each year using C:N ratio and row positions as the independent variables. Analyses of variance and multiple comparisons were made using SAS statistical software (Cary, N.C.).

RESULTS AND DISCUSSION

Grain yield results varied greatly with year but tended to show similar results for both soybean and sorghum. In 1993, after stand establishment was aided by irrigation, the crops weathered brief droughts but received adequate rainfall periodically throughout the growing season (36.6 cm, May-August). Throughout the 1993 growing season, grain sorghum plants in those rows that were not adjacent to the trenches were noted to be of reduced height and with immature heads as compared to those plants adjacent to the trenches. In 1994, rainfall was excessive for most of the growing season (63.0 cm, May-August) resulting in poorer yields. Rainfall was again sparse in 1995, with frequent short-term droughts a common occurrence (21.9 cm, May-August). The grain sorghum experiment was discontinued after the second year due to a lack of response from the trenched areas.

No overall differences were detected in grain yield of the soybeans or the grain sorghum due to differences in the original establishment of the C:N ratio of the waste cellulose material mixture (figs. 3 and 4). This lack of a trend indicates treating the cellulose mixture with additional nitrogen is probably unnecessary. It also suggests that if another waste material rich in nitrogen is available (such as poultry litter) it neither inhibits nor increases plant growth when placed in the subsoiled zone.

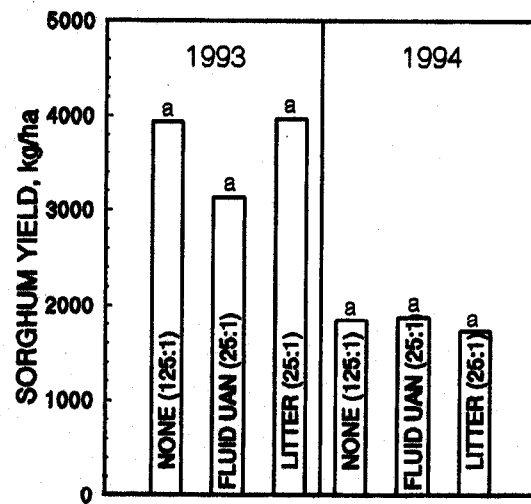


Figure 3-Grain sorghum yields adjacent to trenches filled with cellulose material that had adjusted C:N ratios. Within each year, means with the same letter are not significantly different at $\alpha = 0.05$ (LSD test).

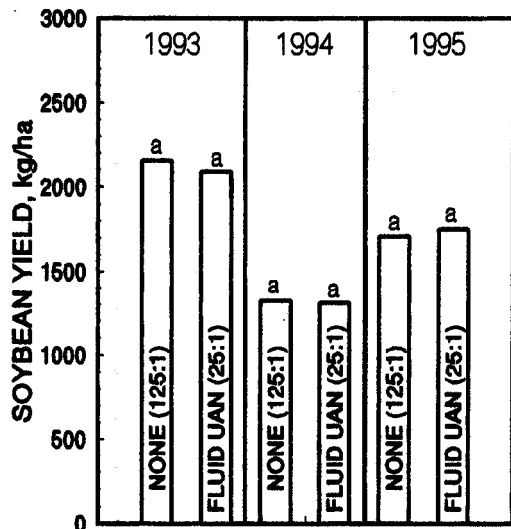


Figure 4-Soybean yields adjacent to trenches filled with cellulose material that had adjusted C:N ratios. Within each year, means with the same letter are not significantly different at $\alpha = 0.05$ (LSD test).

One of the most interesting results is the benefit afforded plants placed in rows alongside the trenches. Grain yields of grain sorghum and soybeans in rows adjacent to trenches (rows 2,3,6, and 7) were significantly greater than those of rows not adjacent to a trench (rows 4 and 5) (figs. 5 and 6). The improved rooting depth afforded by the trench allowed plants adjacent to this zone to take advantage of loose soil conditions and obtain moisture throughout the growing season. The benefits offered by the trench to the plants were substantial except in 1994 when grain sorghum yields were equivalent throughout the entire plot. These results suggest that the excessive rainfall in 1994 negated the trenching effect.

An effort was made to excavate and visually inspect the trenches for rooting activity near the end of the first growing season. Only a small amount of cellulose remained visible in the trenched area, but rooting activity was abundant to the bottom of the trench. Because of

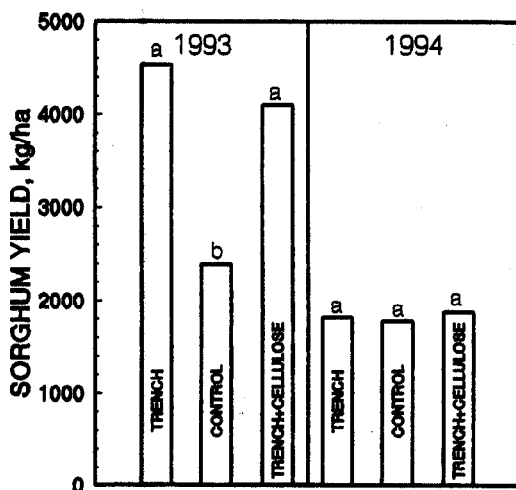


Figure 5-Grain sorghum yield in rows adjacent to trenches (rows 2 and 3 for trench + cellulose and rows 6 and 7 for trench alone) and in control rows (rows 4 and 5). Within each year, means with the same letter are not significantly different at $\alpha = 0.05$ (LSD test).

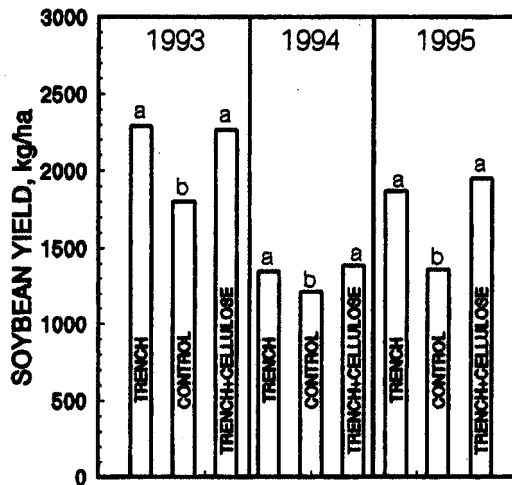


Figure 6-Soybean yields in rows adjacent to trenches (rows 2 and 3 for trench + cellulose and rows 6 and 7 for trench alone) and in control rows (rows 4 and 5). Within each year, means with the same letter are not significantly different at $\alpha = 0.05$ (LSD test).

extremely dry soil conditions, measurements of cone index across the plot gave large values, but the results clearly showed that the effect of the trench was much broader than the 15-cm width of the tillage tool (fig. 7). This was evident in trenches with and without cellulose.

The final set of cone index measurements obtained after the third annual soybean crop showed that the trenched area contained the minimum values of cone index compared to those taken in the row and those obtained halfway between (figs. 8 and 9). Also, there is no indication that the trenched areas not receiving waste cellulose were recompacting. The cone index in this zone is still mostly below the 2 MPa limit that researchers have determined is important for proper root growth (primarily for cotton plants) (Taylor and Gardner, 1963). The average moisture content of the soil in these plots was 9.9%.

CONCLUSIONS

1. An agricultural implement was successfully developed and tested for subsoiling and applying

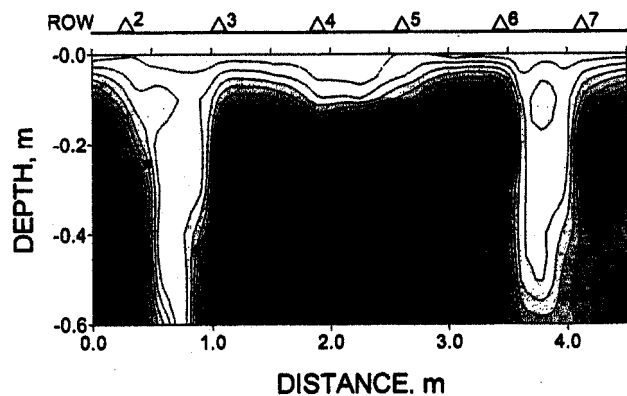


Figure 7-Cone index (MPa) profile taken at end of growing season 1993 across the grain sorghum experiment with the cellulose trench between rows 2 and 3 and the non-cellulose trench between rows 6 and 7. Fluid urea ammonium nitrate was mixed with the cellulose on this plot to achieve a C:N ratio of 25:1.

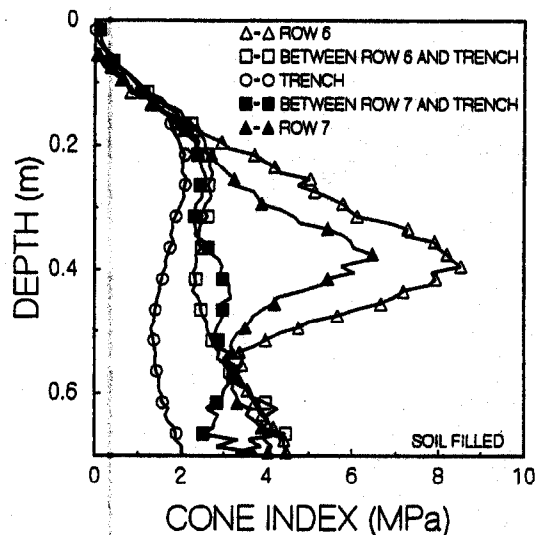


Figure 8—Cone index measurements taken in soybean plots where a trenched zone was constructed midway between rows 6 and 7 and filled with soil three years prior.

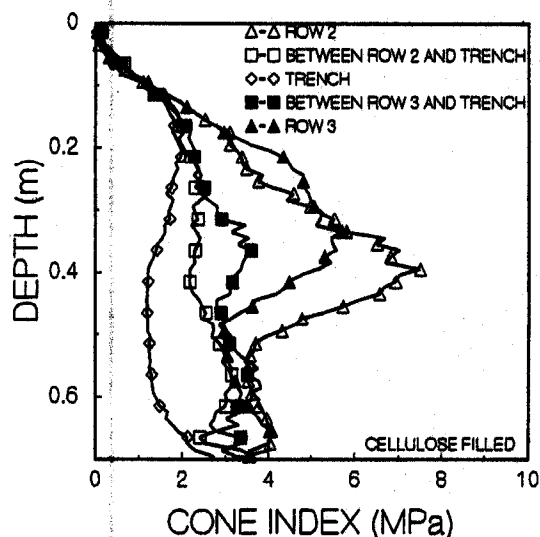


Figure 9—Cone index measurements taken in soybean plots where a trenched zone was constructed midway between rows 2 and 3 and filled with a mixture of soil and cellulose three years prior.

waste materials in one pass. This machine was successfully used to install experiments to examine the feasibility of applying waste cellulose materials in a traditional agricultural field situation.

2. Soybeans and grain sorghum both showed positive responses when placed adjacent to trenched areas as compared to plants placed adjacent to untrenched areas. Plants placed adjacent to a trench containing the waste cellulose mixture were not affected either positively or negatively and grew equally well to those placed adjacent to a trench and refilled with soil.
3. Recompaction of the trenched area has not occurred in plots that contained either the waste cellulose mixture or only soil after three years. Without any surface traffic to reconsolidate these trenched areas, the soil condition in this Coastal Plains soil may be able to withstand natural recompactive forces for several years.

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