

EFFECT OF ROW PROXIMITY TO IN-ROW SUBSOILED ZONES ON COTTON PRODUCTIVITY

R. L. Raper, J. S. Bergtold, E. B. Schwab

ABSTRACT. Producers in the Coastal Plain of the southeastern United States manage soil compaction in conservation tillage systems by in-row subsoiling prior to planting. However, planting directly over the loosened zone of soil can be difficult in high-residue conservation tillage systems where cover crop production is maximized, because the loosened soil is often covered by the large amounts of cover crop residue. Tractors equipped with guidance systems could assist with placement of in-row subsoiling and planting operations, but little is known about the accuracy necessary to maximize rooting development, reduce succeeding soil compaction, and optimize crop yield. An experiment was conducted in south-central Alabama to determine the maximum distance in-row subsoiling performed by three different implements could be from the cotton row without reducing cotton growth and increasing soil compaction. Results showed that if the cotton row was within 5.1 cm of in-row subsoiling, the relative seed cotton yield is 44% greater than a corresponding no-subsoiling treatment. No significant differences were found between the three in-row subsoiling implements used in the experiment. Recommendations resulting from this experiment indicate that to maximize crop yields and minimize soil compaction in the row, the subsoiled zone should be kept within 5 cm of the row.

Keywords. Subsoiling, Soil compaction, Strip-tillage, Conservation tillage, Precision agriculture.

High-residue conservation tillage systems are becoming an important tool for farmers in the sandy Coastal Plain soils of the southeastern United States who want to conserve soil moisture and increase soil organic matter (Campbell et al., 1974; Reeves, 1994). However, soil compaction either caused by naturally occurring compaction or due to uncontrolled traffic with heavy equipment in these soils can reduce crop yields (Raper et al., 1994). This problem can be rectified via strip-tillage or in-row subsoiling (Reicosky et al., 1977; Box and Langdale, 1984; Hammond and Tyson, 1985; Busscher and Sojka, 1987; Garner et al., 1987; Mullins et al., 1997; Raper et al., 1998) as part of a conservation system while maintaining adequate surface residue. In-row subsoiling disrupts compacted soil profiles in a narrow zone under the row, allowing roots to proliferate downward to obtain adequate soil moisture (Raper, 2005).

In the high-residue conservation tillage systems on Coastal Plain soils, in-row subsoiling is commonly implemented in the spring between termination of the cover crop and planting operations. To maximize benefits of the disrupted soil profile, producers attempt to plant directly over

the loosened zone created by the in-row subsoiling operation. Planting directly in the middle of the loosened zone can be difficult, especially with large amounts of aboveground biomass resulting from the cover crop and from in-row subsoiling implements that do little surface disruption. Also, vehicle traffic that is not controlled and allowed to become near the disrupted profile can cause recompaction, reducing or eliminating the benefits associated with in-row subsoiling (Dumas et al., 1973; Raper et al., 1994).

Other options that include using row markers may be ineffective in penetrating through residue and leaving visible marks above the cover crop residue. Another option that has sometimes been used is to combine the in-row subsoiling operation and the planting operation, however, the resulting implement is larger and more cumbersome. Another problem that frequently occurs with this combined approach is that if an intense rainfall occurs immediately after planting, the seeds can fall into the disturbed slot and may not emerge. A small period of time between the in-row subsoiling operation and the planting operation which often includes a rain in our climate may be helpful to reduce this emergence problem.

Maintaining close proximity between the subsoiled zone and the planted row over an entire field requires some form of automatic steering technology. Tractors with this capability commonly use real time kinematic-global positioning systems (RTK-GPS) which allow for repeatable paths with 2-3 cm precision (Trimble Navigation Limited, 2001). However, the cost of automatic steering technology can be prohibitive for many producers. Furthermore, little is known about how the precision of these systems affects soil compaction or crop yield. Therefore, an experiment on a Coastal Plain soil was conducted to determine the distance between cotton rows and in-row subsoiled zones that would maximize crop production and minimize soil compaction in high-residue conservation tillage systems.

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The objectives of this experiment were:

To determine the effect of row proximity between in-row subsoiled zones and planted rows on seed cotton yields, and soil bulk density.

To determine the effect of alternative in-row subsoiling implements on seed cotton yields and soil bulk density at varying row proximity.

METHODS AND MATERIALS

In September of 2002, a field with a pronounced soil hardpan beginning at 20 cm and extending down to an approximate depth of 30 cm was selected at the Field Crops Unit of the E.V. Smith Research Center in Shorter, Alabama. The soil type is a Compass loamy sand (Coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) with less than 2% slope. A rye (*Secale cereale* L.) cover crop was planted with a 3-m Marlist Pasture King grain drill in October of 2002 and in all subsequent years.

In March of 2003 and in all subsequent years, the cover crop was terminated at the soft dough stage by an application of glyphosate and was rolled using an experimental cover crop roller (Raper et al., 2004; Raper and Simionescu, 2004). Within two weeks of cover crop termination, in-row subsoiling at a depth of 36 cm was performed with a John Deere (Deere & Co., Moline, Ill.) 8300 tractor equipped with a Trimble AgGPS Autopilot system (Sunnyvale, Calif.) which has reported automatic steering accuracy of ± 2.54 cm. The rear tires on the tractor were 18.4R46 while the front tires were 16.9R30 and all were inflated to 82 kPa. The same tractor and a John Deere 1700 4-row planter was used to plant the cotton (Stoneville 4892 BT/RR) at a slight angle to the deep tillage rows. At one end of the field, the cotton was planted directly over the in-row subsoiled zone. As the planter traveled through the field, it deviated towards the row middle with the cotton being planted midway between the in-row subsoiled zones at the other end of the field (fig. 1). The field (126.5 m long) was divided parallel to the rows into 12 (9.1 m) plots with 11 (1.5 m) borders. This setup resulted in 12 plots with varying ranges of distances between the cotton row and the in-row subsoiled zone (row proximity distance), enabling the evaluation of row proximity on

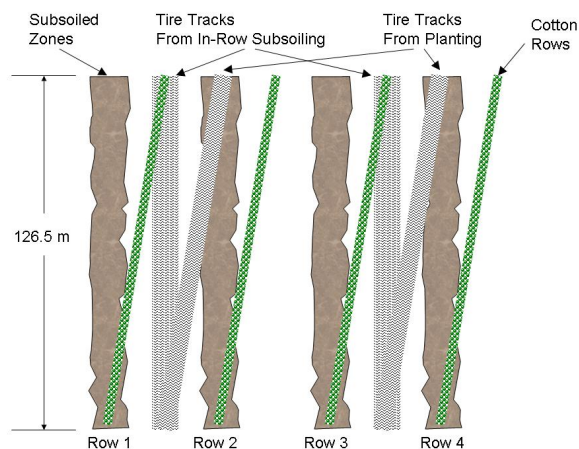


Figure 1. Experimental layout showing how cotton rows were directly on top of subsoiled zones at one end of field and deviated to the row middle at the other end of the field.

cotton yield and soil compaction. The midpoints (range) of the row proximity distances examined in each plot were 0.6 cm (-1.3 to 1.9 cm), 5.1 cm (3.2 to 6.4 cm), 9.5 cm (7.6 to 10.8 cm), 14.0 cm (12.1 to 15.2 cm), 18.4 cm (16.5 to 19.7 cm), 22.9 cm (21.0 to 24.1 cm), 27.3 cm (25.4 to 28.6 cm), 31.8 cm (29.8 to 33.0 cm), 36.2 cm (34.3 to 37.5 cm), 40.6 cm (38.7 to 41.9 cm), 45.1 cm (43.2 to 46.4 cm), and 49.5 cm (47.6 to 50.8 cm).

The three-year study was designed to compare the effects of the row proximity of in-row subsoiling to the planted row in four different conservation tillage systems. Each conservation tillage system used an alternative subsoiling implement to perform tillage operations. These included a Kelley Manufacturing Company's (Tifton, Ga.) Rip/Strip in-row subsoiler, a Bigham Brothers' (Lubbock, Tex.) Paratill[®] bentleg subsoiler, a Worksaver (Litchfield, Ill.) Terra-Max I[®] bentleg subsoiler, and a no-subsoiling treatment (control). Each tillage system was replicated four times and was present in all 12 plots with varying row proximity distances (192 plots). The plots were 4 rows wide with 1-m row spacing for both in-row subsoiling and planting.

Seed cotton yield was used to evaluate the tillage systems. A John Deere 9920 cotton picker was used to bag the center two rows of every plot. To reduce the impact of field variability, the relative seed cotton yield was calculated by dividing the cotton yield for each tillage treatment by the cotton yield obtained from the nearby no-subsoiling treatment. This procedure allowed direct comparisons to be made between the various row proximities along the entire length of the field.

Climate affected plant productivity and harvest. In 2003, weather delayed planting until 30 May, delaying harvest until 29 October, adversely affecting cotton boll development and seed cotton yields. Cotton was planted on 5 and 12 May and harvested on 22 September and 1 October for 2004 and 2005, respectively. Damaging rain and winds from Hurricane Ivan reduced seed cotton yields in 2004. Rainfall during the growing season (May to October) was 841 mm in 2003, 689 mm in 2004, and 571 mm in 2005.

Due to the occurrence of Hurricane Ivan in 2004 and the resulting crop reductions, plant height measurements were also taken to assist in determining the influence of the various tillage treatments for this growing season. Five different row proximity positions were evaluated with the following midpoints from the in-row subsoiled zones; 0, 13, 21, 34, and 48 cm. Ten plants were taken from the areas surrounding these midpoints and measured for height from the soil surface to the most fully opened leaf.

Bulk density measurements were obtained by taking a soil core of 7.6-cm diameter (Raper et al., 1999) directly in the path of the shank in the fall of 2005 following cotton harvest. Three cores per plot were obtained and analyzed for bulk density at five different depth increments: 0-5.1 cm, 10.2-15.2 cm, 20.3-25.4 cm, 30.5-35.6 cm, and 35.6-40.6 cm.

The experimental design was a randomized complete block with four conservation tillage systems as treatments. Mixed model methodology as implemented in SAS Proc Mixed (Littell et al., 1996) was used to analyze the data at each of the 12 row proximity distances based on the described design. A predetermined significance level of $P \leq 0.10$ was

selected and Fisher's least-significant-difference test (LSD) was used to examine means separation.

RESULTS AND DISCUSSION

SEED COTTON YIELD

Seed cotton yield varied significantly with year due to variations in climatic conditions. Yields of the no-subsoiling treatments were reduced compared to the three in-row subsoiling treatments at all row proximity positions, which illustrated why in-row subsoiling is such a valuable cultural practice in this region (figs. 2, 3, and 4).

In 2003, 10 of the 12 row proximity distances showed significantly reduced seed cotton yields for the no-subsoiling treatment as compared to the in-row subsoiling treatments (fig. 2). Only small differences were found between the in-row subsoiling treatments with most being equivalent at all row proximity positions.

In 2004, yields were reduced due to Hurricane Ivan, but showed similar trends to 2003 (fig. 3). No-subsoiling seed cotton yields were significantly reduced at 7 of 12 row

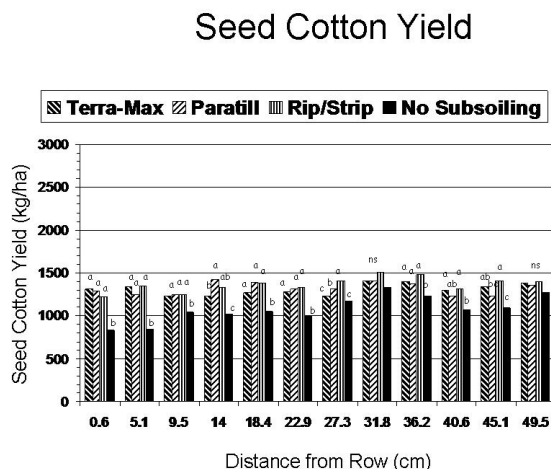


Figure 2. Mean seed cotton yields by subsowing treatment, 2003.

Seed Cotton Yield

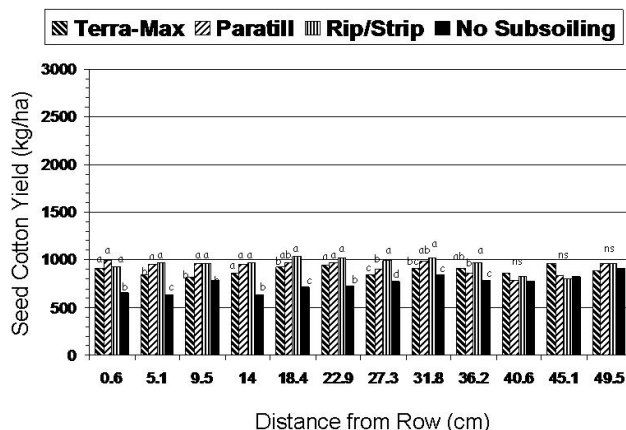


Figure 3. Mean seed cotton yields by subsowing treatment, 2004.

Seed Cotton Yield

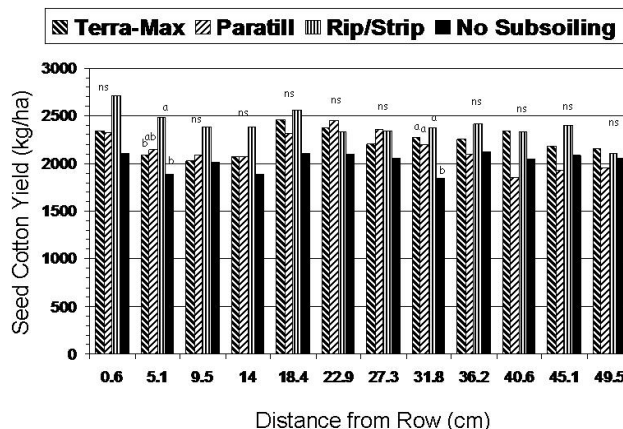


Figure 4. Mean seed cotton yields by subsowing treatment, 2005.

proximity distances when compared to seed cotton yields from all in-row subsoiling treatments. As in 2003, little difference was noted among the three subsoiler types.

In 2005, the highest seed cotton yields from the experiment were measured (fig. 4). Lower seed cotton yields were mostly found with the no-subsoiling treatment, however in 2005, the differences were mostly non-significant with one exception (31.8-cm row proximity). A trend was noted when row proximity was less than 18.4 cm that indicated that the Rip/Strip in-row subsoiler showed higher seed cotton yields than the other tillage treatments. However, only one row proximity position (5.1 cm) was statistically significant.

RELATIVE SEED COTTON YIELD

In 2003, only one row proximity position (27.3 cm) indicated a statistically significant difference between the in-row subsoilers with the Rip/Strip implement having the greatest relative seed cotton yield (fig. 5). A general trend was noted, however, in decreasing relative seed cotton yields as the row proximity increased with three distinct ranges of

Relative Seed Cotton Yield

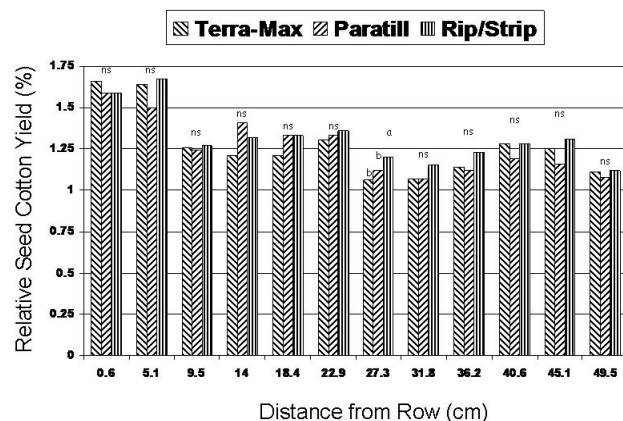


Figure 5. Relative seed cotton yields of in-row subsowing treatments compared to nearby corresponding no-subsoiling treatments from 2003.

row proximities emerging. Between 0.6 to 5.1 cm of row proximity, average seed cotton yield was 61% greater than the corresponding no-subsoiling seed cotton yield. As the row proximity increased from 9.5 to 22.9 cm, the average seed cotton yields were only 30% greater than the corresponding no-subsoiling seed cotton yield. In the third distinct row proximity range, which occurred from 27.3 to 49.5 cm, seed cotton yields were 16% greater than the corresponding no-subsoiling seed cotton yield

In 2004, relative seed cotton yields were similar to 2003, even though a hurricane significantly reduced seed cotton yields (fig. 6). Among subsoiling treatments, the Rip/Strip in-row subsoiler was statistically greater than the Terra-Max at 4 row proximity distances, and greater than the Paratill at 3 row proximity distances. A similar trend was noted with declining relative yields as row proximity increased. The row proximity distances and corresponding yield increases were: 0-6 to 5.1 cm - 50%, 9.5 to 22.9 cm - 37%, and 27.3 to 49.5 cm - 15% greater than the corresponding no-subsoiling seed cotton yields, respectively.

In 2005, the relative seed cotton yields were smaller than those calculated for previous years, probably due to the more timely rainfall, higher temperatures, and generally improved seed cotton yields associated with the no-subsoiling treatments (fig. 7). The Rip/Strip in-row subsoiler showed a trend toward having greater yields in 8 of the 12 row proximity locations. Relative seed cotton yield did not decline dramatically as row proximity increased during 2005.

Averaged across all three years of the experiment, the row proximity distance had an effect on relative seed cotton yield (fig. 8). The same three regions produced similar relative seed cotton yields (0.6-5.1 cm, 9.5-22.9 cm, and 27.3-49.5 cm) by examining the average data. The greatest relative seed cotton yield was in the 0.6 to 5.1 cm range which was 44% greater than the corresponding no-subsoiling cotton yield. Average relative seed cotton yields in the 9.5- to 22.9-cm range were reduced to 28% greater compared to the corresponding no-subsoiling cotton yield. Roots growing in this region do not have the obvious advantages of growing

Relative Seed Cotton Yield

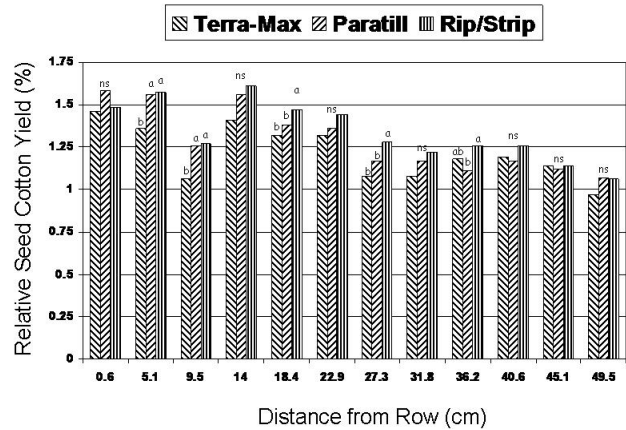


Figure 6. Relative seed cotton yields of in-row subsoiling treatments compared to nearby corresponding no-subsoiling treatments from 2004.

directly in the center of the in-row subsoiled zone. Average relative seed cotton yields were decreased even more in the 27.3- to 49.5-cm range to only 14% greater than the corresponding no-subsoiling cotton yield. At this distance from the in-row subsoiled zone, the roots were too far away to adequately benefit the cotton plants. Additionally, a non-significant trend was noted with the Rip/Strip having the highest three-year average relative seed cotton yield compared to the Paratill or the Terra-Max at every row proximity distance.

PLANT HEIGHT

The plant height data (fig. 9) that was taken to assist in explaining seed cotton yield for 2004 came to similar conclusions as the seed cotton yield data (fig. 3). Plant heights from no-subsoiling treatments were significantly reduced from the in-row subsoiling treatments at row proximity distances of 0 to 21 cm. At row proximity distances of 34 cm and greater, no differences were found in any tillage

Relative Seed Cotton Yield

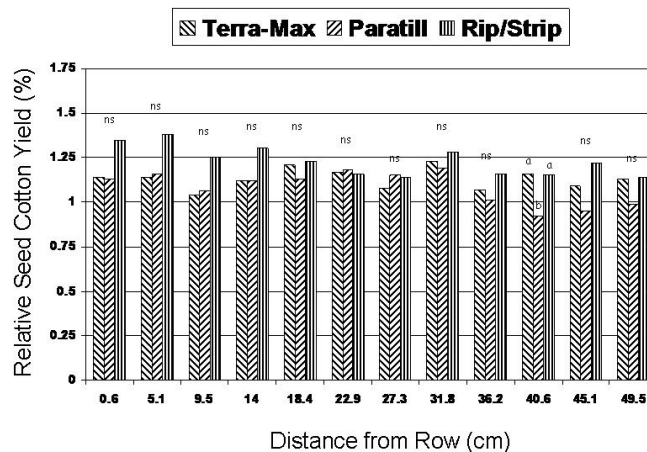


Figure 7. Relative seed cotton yields of in-row subsoiling treatments compared to nearby corresponding no-subsoiling treatments from 2005.

Relative Seed Cotton Yield

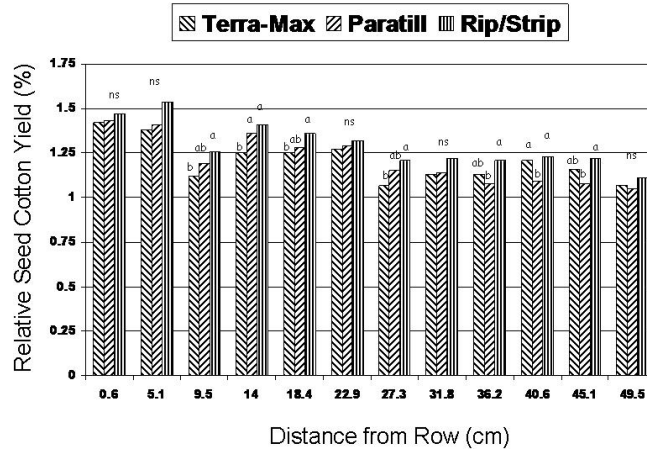


Figure 8. Relative seed cotton yields of in-row subsoiling treatments compared to nearby corresponding no-subsoiling treatments averaged from 2003-2005.

Plant Height

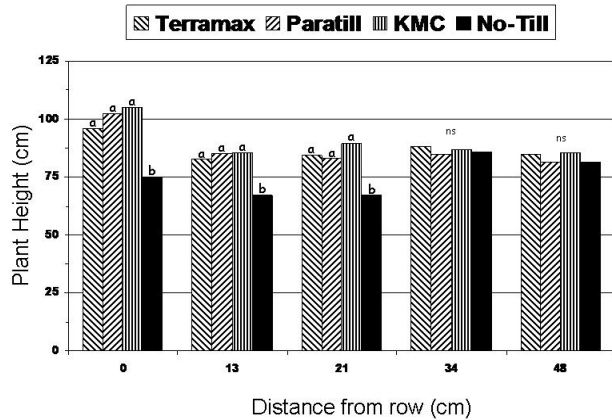


Figure 9. Height of cotton plants taken in 2004.

treatment. The largest reduction in plant height was also noted at the 0-cm row proximity compared to any other row proximity distance. This finding supports the relative seed cotton yield data for this same year (2004) which indicated yield reductions occurred if the row proximity exceeded 5.1 cm.

BULK DENSITY

Because the experiment was maintained in the same location, changes in bulk density were the result of cumulative effects over the three years of the experiment. Bulk density measurements taken directly over the position of in-row subsoiling (0-cm row proximity) showed significant amounts of soil loosening, even though tillage treatments were performed 6 months earlier (fig. 10A). The lowest values of bulk density were measured near the soil surface where the Terra-Max and the Paratill had statistically similar values. The Rip/Strip implement had slightly higher values of bulk density and was significantly different from the Terra-Max. The greatest bulk density values were

associated with the no-subsoiling treatment which was similar to those obtained with the Rip/Strip treatment.

At the next depth of 13 cm at the 0-cm row proximity position (fig. 10A), no statistical differences were found, with the no-subsoiling treatment having maximum values and the Terra-Max treatment having minimum values. At a depth of 23 cm, the Terra-Max had the lowest bulk density value, but was similar to the Paratill. Furthermore, there was no significant difference between the Paratill, Rip/Strip, and no-subsoiling treatments at this depth. At the 38-cm depth, the Terra-Max and the Paratill were again similar with the Rip/Strip and no-subsoiling bulk density values being the largest and statistically similar.

A greater amount of soil loosening was achieved at the 0-cm row proximity (fig. 10A) with the bentleg subsoilers (Terra-Max or the Paratill). These subsoilers achieved longer lasting results than was achieved with the Rip/Strip implement. Bulk density values measured under the Rip/Strip treatment were closest to those with the no-subsoiling treatment.

At the other three row proximity positions [10 cm (fig. 10B), 27 cm (fig. 10C), and 50 cm (fig. 10D)], no statistical differences were found between any of the three in-row subsoiling treatments or the no-subsoiling treatment. At the 10-cm row proximity position, the no-subsoiling treatment did tend to have the greatest bulk density values, particularly near the soil surface.

This study illustrates why controlled traffic is a useful technology for our Southeastern U.S. soils. Even with the natural compaction problems that exist within our soil types and climate, the additional compaction pressure caused by wheel tracks negatively affects crop productivity. Also, noted is the necessity of using some form of in-row subsoiling which alleviates soil compaction caused by natural processes and vehicle traffic. The results of this study point to the particular benefits for the crop offered by the Rip/Strip in-row subsoiler with higher trends in seed cotton yield when averaged over the three years of the study. However, these benefits may have been relatively short-lived as the bulk density measurements actually found decreased values of bulk density for the Paratill and Terra-Max in-row subsoilers

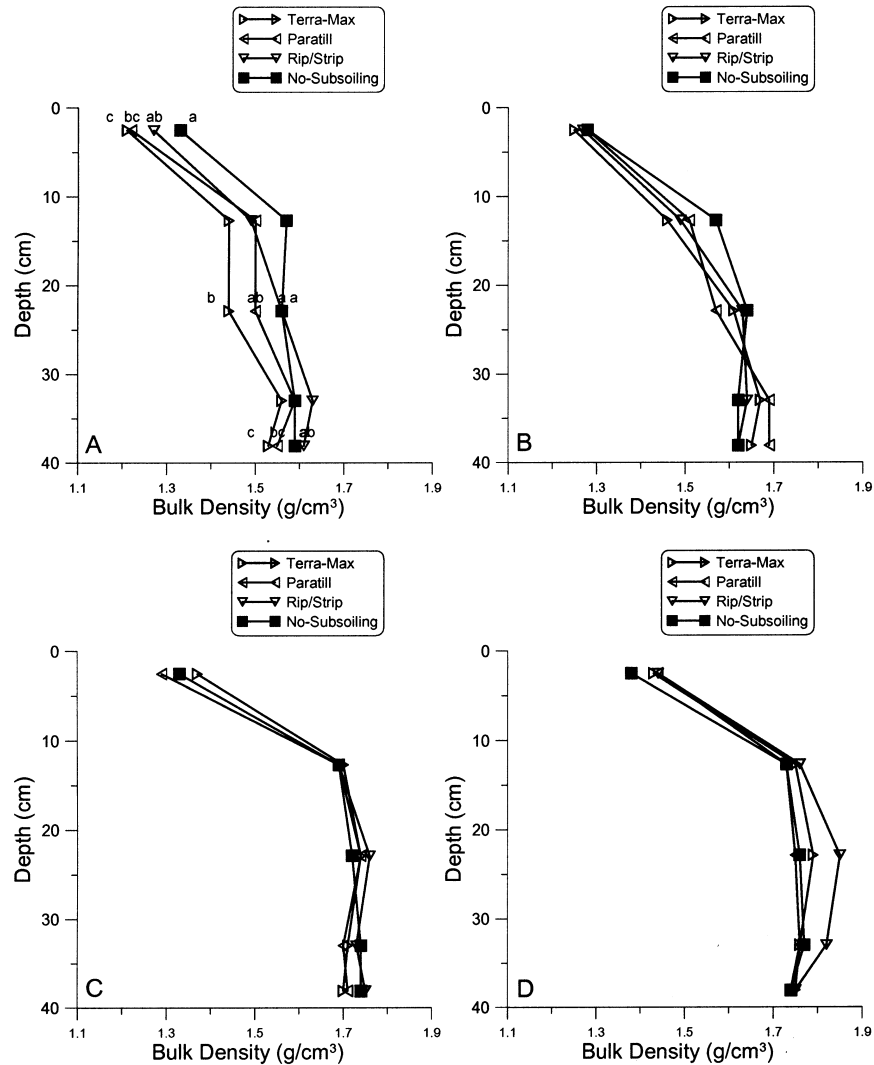


Figure 10. Bulk density measurements taken after harvest in 2005 at different row proximities: (A) 0-cm row proximity, (B) 10-cm row proximity, (C) 27-cm row proximity, and (D) 50-cm row proximity.

which were taken 6 months after the tillage event. The Rip/Strip implement, which disturbs large amounts of soil in the in-row position as opposed to the bentleg subsoiler, may offer better growing conditions for the plant early in the growing season due to its increased loosening. However, this looser soil condition also consolidates quicker as illustrated by the bulk density measurements taken 6 months after tillage.

The primary emphasis of this research effort is the importance of maintaining close proximity to the in-row subsoiled position with the planter even when large amounts of cover crop residue are present. As the row deviates from the previously in-row subsoiled position, significant losses in crop yield can occur, especially when the crop, such as cotton, is sensitive to soil compaction. Being able to maintain the two separate operations (in-row subsoiling and planting) over large areas of a field within row proximities of 0 to 5.1 cm is difficult without the use of a RTK automatic steering system.

CONCLUSIONS

- In-row subsoiling increased seed cotton yields compared to no subsoiling at almost all row proximity positions. Only when the rows were near the row middles and far away from the in-row subsoiled zones did the seed cotton yields become similar. In general, seed cotton yields were greatest where the proximity between the row and the in-row subsoiled zone was smallest and decreased as the row proximity increased.
- The relative seed cotton yield was greatest (44% greater than the corresponding no-subsoiling treatment) when the row proximity was 5.1 cm or less. As the row proximity increased to 9.5-22.9 cm, the relative seed cotton yield declined to 28% greater than the corresponding no-subsoiling treatment. At the greatest row proximity distance range of 27.3-49.5 cm, the relative seed cotton yield was only 14% greater than the corresponding no-subsoiling treatment.
- No significant differences were found in seed cotton yield due to the three in-row subsoiling implements, however, a trend indicated that higher average yields were found with

the Rip/Strip implement while reduced bulk densities were found with the Paratill and the Terra-Max.

- Bulk density values taken in the fall, after the third harvest year showed longer-lasting benefits associated with the use of the bentleg subsoilers (Paratill or Terra-Max) used in the spring. However, these implements' use did not increase seed cotton yield above the Rip/Strip subsoiler. Also, increased bulk density values throughout the entire soil profile were found as the row proximity increased.
- To maximize crop yields and minimize soil compaction in the row, the subsoiled zone should be kept within 5 cm of the row. Precision of ± 5 cm would be necessary from an automatic-steered tractor to obtain these results.

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