Reduction of Soil Compaction in a Cotton and Peanut Rotation Using Conservation Systems

R.P.Simoes[1], R.L. Raper[2], F.J. Arriaga[2], K.S. Balkcom[2] and J.N. Shaw[1]

Corresponding author's email address: simoerp@auburn.edu

ABSTRACT

Southern Coastal Plain soils benefit from the adoption of conservation tillage systems as water retention and organic matter increase which improves soil structure. However, some Coastal Plain soils are prone to compaction and tend to form hardpans which restrict root growth and reduce yields. The adoption of non-inversion deep tillage has been recommended to disrupt compacted soil layers and create an adequate medium for crop development. In spite of its efficacy, increased fuel prices have many producers questioning in-row subsoiling as too expensive. This has led to research on development of subsoiler shanks that minimally disrupt soil surface and require reduced horsepower. Three subsoiling implements were evaluated against a no-subsoiled treatment with and without a rye cover crop at the Wiregrass Research Station in Headland, AL on a Dothan loamy sand soil. Plant, soil and machinery parameters were evaluated: crop yield, cover crop biomass, cotton leaf temperature, soil moisture, bulk density, and cone index. Results showed consistently lower yields for no-subsoiled treatments. In one year of the study which was dramatically affected by drought, significantly increased yields were found with the use of a cover crop. No differences between implements were found.

INTRODUCTION

Conservation tillage has been used to reduce soil erosion and decrease production costs worldwide. In the southeastern USA, conservation systems are used on approximately 50% of the 7.2 million acres of cotton (*Gossypium hirsutum L.)* planted in 2004 (CTIC, 2005). Another important southeastern US crop, peanut (*Arachis hypogaea L.*), has shown an increased acreage of 80,000 acres under conservation systems from 2002 to 2004. In 2005, peanut was planted on 1.3 million acres in the Southeast with 55% of the total area being in rotation with cotton (CTIC, 2005).

Southern Coastal Plain soils show benefits when producers adopt conservation systems due to increased water retention, increased organic matter, and improved soil structure (Reeves, 1994; Ess et al.,1998; Raper et al., 2000a; Raper et al., 2000b). However, these soils have a natural susceptibility to compaction and tend to form hardpans extending from the surface Ap to the transitional E horizon, restricting root growth and reducing yields (Busscher et al., 1996; Raper et al., 2005). These hardpans are a product of soil reconsolidation which may occur through multiple cycles of wetting and drying causing the soil bulk density to increase (Mapa et al., 1986; Assouline, 2006). The formation of these hardpans may cause the transition from conventional to no-tillage systems more difficult as deep tillage may always be required.

---

[1]Department of Agronomy and Soils, Auburn University, 36849

[2]USDA-ARS National Soil Dynamics Laboratory, Auburn, AL 36832

The adoption of non-inversion deep tillage has been recommended to disrupt compacted soil layers and create an adequate medium for crop development (Reeder et al., 1993; Khalilian et al., 1988; Raper, 2005). Even though in-row subsoiling has been shown to ameliorate effects of compaction, it is still considered to be an expensive operation, especially with increased fuel prices. Additional research is needed to investigate alternative methods of in-row subsoiling which may reduce energy use and produce optimum crop yields. Additionally, due to the extensive soil disruption that takes place with peanut harvesting, this study will also determine if additional in-row subsoiling is beneficial after this harvesting process.

The objectives of this study were to compare three different subsoiling implements against a strict no-till system where a winter rye crop *(Secale cereale L.)* was used as a cover crop in a four-year cotton-peanut rotation in a highly compactable southern Coastal Plain soil.

MATERIALS AND METHODS

This study started in fall of 2002 at the Wiregrass Research and Extension Center in Headland AL with the planting of a cover crop. The soil type is Dothan fine-loamy, kaolinitic, thermic Plinthic Kandiudults; this soil series is extensive and is distributed throughout the Coastal Plain of Alabama, Florida, Georgia, North Carolina, South Carolina, and Virginia. The site has a 0 to 1% slope and has been cropped for many years under conventional tillage.

The experimental design was a split-plot with four replications and treatments were arranged in a two by four factorial. The two factors were a rye *(Secale cereale L.)* winter cover crop (cover or no cover) and in-row subsoilng (no-till and three subsoiler treatments). In-row subsoiling was implemented at 15 in depth using the following implements: KMC[3] strip-till (Kelley manufacturing Co., Tifton GA); Paratill (Bigham Brothers, Inc., Lubbock, TX); and Terramax Worksaver (Worksaver Inc., Litchfield, IL).

Rye cover crop was sprayed with 1qt/ac of glyphosate and mechanically terminated using a roller prior to spring planting. The variety of peanut planted was Georgia Green in 2003 and 2005, while the variety of cotton planted was the transgenic Delta Pine 555 BG/RR triple stacked for 2004 and 2006. Peanuts and cotton were planted with a John Deere 1700 (Deere & Company, Moline, IL) 4-row vacuum planter. Cotton received 90 lb/ac of nitrogen, 90 lb/ac of potassium and 20 lb/ac of sulfur while the peanut crop received no fertilization.

Volumetric water content was determined using the dielectric method using the ECHO probes (Decagon Devices Inc, Pullman WA) installed in the planted rows at 12 in depth. These probes were connected to an EM5 data logger (Decagon Devices Inc, Pullman WA) recording moisture values for the 2006 growing season. Volumetric water content was collected for the 2006 cotton crop from June to August. These probes were 8 in long and were placed below the planting row at 14 in depth at a 45 degree angle so the depth of reading was from 11 to 16.5 in.

A tractor-mounted, hydraulically-driven, soil cone penetrometer was used for determination of soil strength after subsoiling and planting in 2003, 2004, 2005, and 2006 (Raper et al., 1999).

---

[3]The use of company names or tradenames does not indicate endorsement by Auburn University or USDA-ARS.

The tractor-mounted penetrometer determined soil strength in five positions simultaneously: (i) in-row, (ii) 9 in from the row in the trafficked middle, (iii) 18 in (midway) from the row in the trafficked middle, (iv) 9 in from the row in the nontrafficked middle, and (v) 18 in (midway) from the row in the nontrafficked middle. A cone with a base area of 0.2 sq. in was used on each of the penetrometers (American Society of Agricultural Engineers, 1998). Three readings per plot were taken continuously (25 points per second) throughout the soil profile to a depth of 16 in. The cone index data were then averaged every 2 in for statistical analysis and for graphs.

The same soil sampling unit was used to obtain measurements of bulk density at 2-in depth increments following harvest of the 2006 crop. A total of 45 cores per plot were taken at three positions: (i) in-row, (ii) trafficked middle and (iii) nontrafficked. Within each position, soil bulk density values were taken at the following depths: (i) 0-2 in; (ii) 2-4 in; (iii) 4-6 in; (iv) 8-10 in and (v) 12-14 in.

Cotton leaf temperature was recorded weekly using Raynger MX (Raytek Corporation, Santa Cruz, CA) hand-held infrared thermometer during the 2006 at cotton blooming. Leaf temperature can be correlated to plant moisture stress and consequently grow performance and productivity (Pettigrew, 2004).

Harvesting of cotton consisted of picking the two middle rows with a John Deere 9910 (Deere & Company; Moline, IL) two row cotton harvester. Peanut was harvested with a Hustler 5000 (Gregory Manufacturing, Lewiston Woodville NC) in the two middle rows. The amount of cover crop above-ground biomass was determined prior to termination from 2004 to 2006 by two 2.68 ft^2 area samples from each plot.

Data was subjected to ANOVA using Statistical Analysis System (SAS Institute, 1988), where it was analyzed by year due to the crop rotation. Multiple means comparisons were done by using Fisher's protected LSD and Least Square Means at significance level of $P< 0.1$.

RESULTS AND DISCUSSION

Cover Crop Biomass

The use of winter cover can have a positive impact on soil quality that is accomplished by increasing soil organic matter, aggregate stability, water retention, and consequently reducing soil bulk density and soil strength (table 1). Our results showed that cover crop production was substantially lower in the no-till treatment from 2004 through 2006 compared to any other treatment. However, in 2005, this difference was not statistically significant which could be explained by a shorter growing period for the 2005 year of 175 days. In 2004, the growing season was 189 days and in 2006 it was 185 days. There were no significant differences among the subsoiling implements for any year of the study. These results confirmed the expected outcome that subsoiling increased cover crop production.

Table1. Rye dry matter production as affected by deep tillage.

Subsoiling Treatment	2004	2005	2006
		lb.ac^{-1}	
No-Till	3107 b	2098a	2062 b
Worksaver	4758 a	2544a	3892 a
Strip-Till	4294 ab	2678a	4107 a
Paratill	4035 ab	2437a	3642 a
LSD(0.10)	1303	1142	892

Soil Moisture

Soil moisture results showed that no statistical difference was found among tillage treatments. The presence of a cover crop, however, had a pronounced effect on soil water content (table 2) with much greater soil moisture being present throughout the growing season as compared to the no cover treatment.

Table 2. Soil volumetric water content as affect by rye cover crop for the 2006 cropping season.

	Volumetric water content %		
Week	Cover	No cover	LSD (0.10)
29-Jun	21.2	17.6	NS
6-Jul	22.5	17.7	3.7
13-Jul	21.4	15.3	3.9
20-Jul	19.0	13.9	4.3
27-Jul	21.3	16.1	3.5
3-Aug	20.0	15.1	3.7
10-Aug	20.3	15.3	4.0
17-Aug	18.0	13.7	3.5
24-Aug	17.0	13.7	NS

Soil Compaction

Only the data from the most recent cone index sampling for each crop will be shown. The data presented was taken immediately after in-row subsoiling was completed in the spring. There were no significant main effects despite the clear differences in the graphs that showed that no-till treatment had the greatest compaction based on increased cone index values (figs. 1 and 2). However, an important interaction occurred involving depth x position x subsoiling for both crops ($P < 0.0001$ for cotton and $P < 0.0001$ for peanuts). These graphs show that subsoiling effectively reduced soil compaction. Paying particular attention to the in-row position for cotton (fig. 1), it is clear that the cone index for the no-till tillage treatment is much greater than any of the other tillage treatments that received subsoiling. As an example, at the 4 in depth the no-till treatment had cone index of 532 psi which was significantly greater than any of the other in-row subsoiling treatments; KMC strip-till (130 psi), Paratill (209 psi), and Worksaver (178 psi). These values confirm that in-row subsoiling was effective in reducing soil strength to below 290 psi which is considered to be detrimental to cotton root development (Taylor and Gardner, 1963).

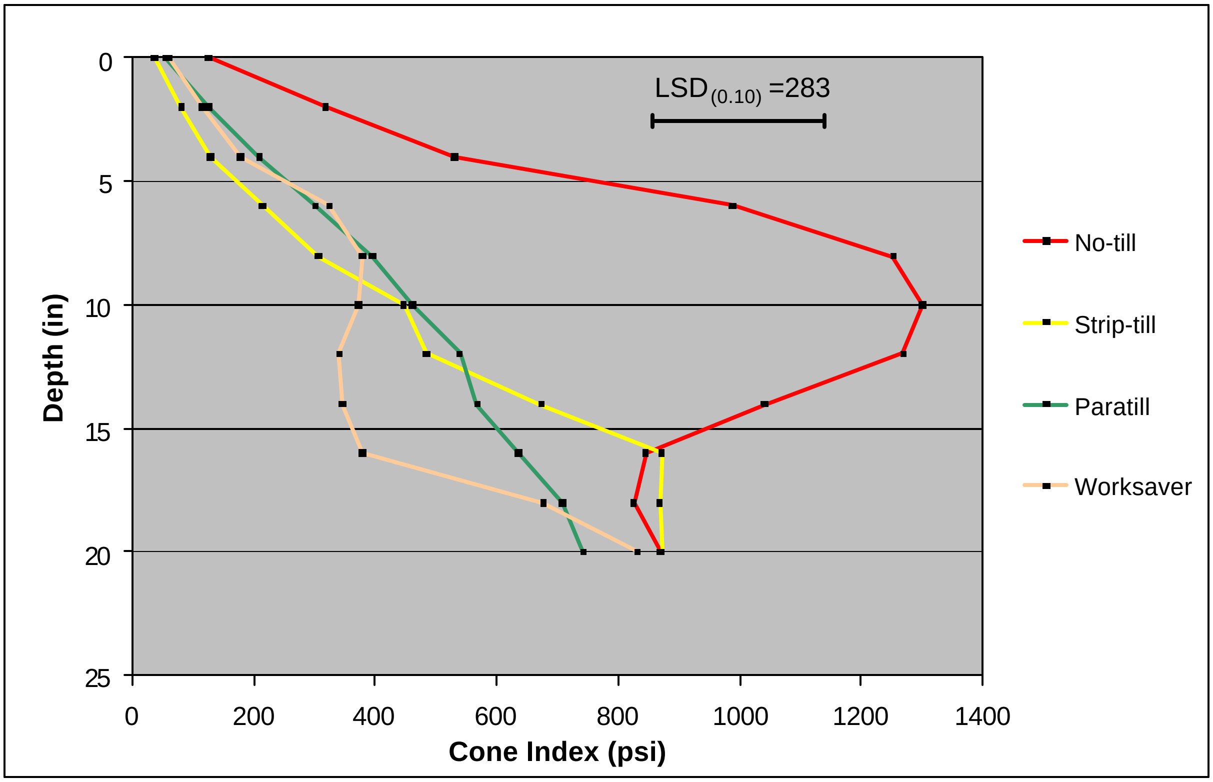

Figure1. Soil cone index values at in-row position for cotton in 2006.

Similar information for cone index for peanut is shown in figure 2. The no-till treatment had the highest values of cone index which reached the limiting value of 290 psi at an approximate depth of 5 in for the in-row position. As an example, at the 6 in depth we observed that the no-till treatment had cone index value of 702 psi which was significantly greater than either the KMC strip-till (20 psi), the Paratill (249 psi) or the Worksaver (24 psi). Coincidentally, the LSD values were nearly the same for peanut and cotton analysis.

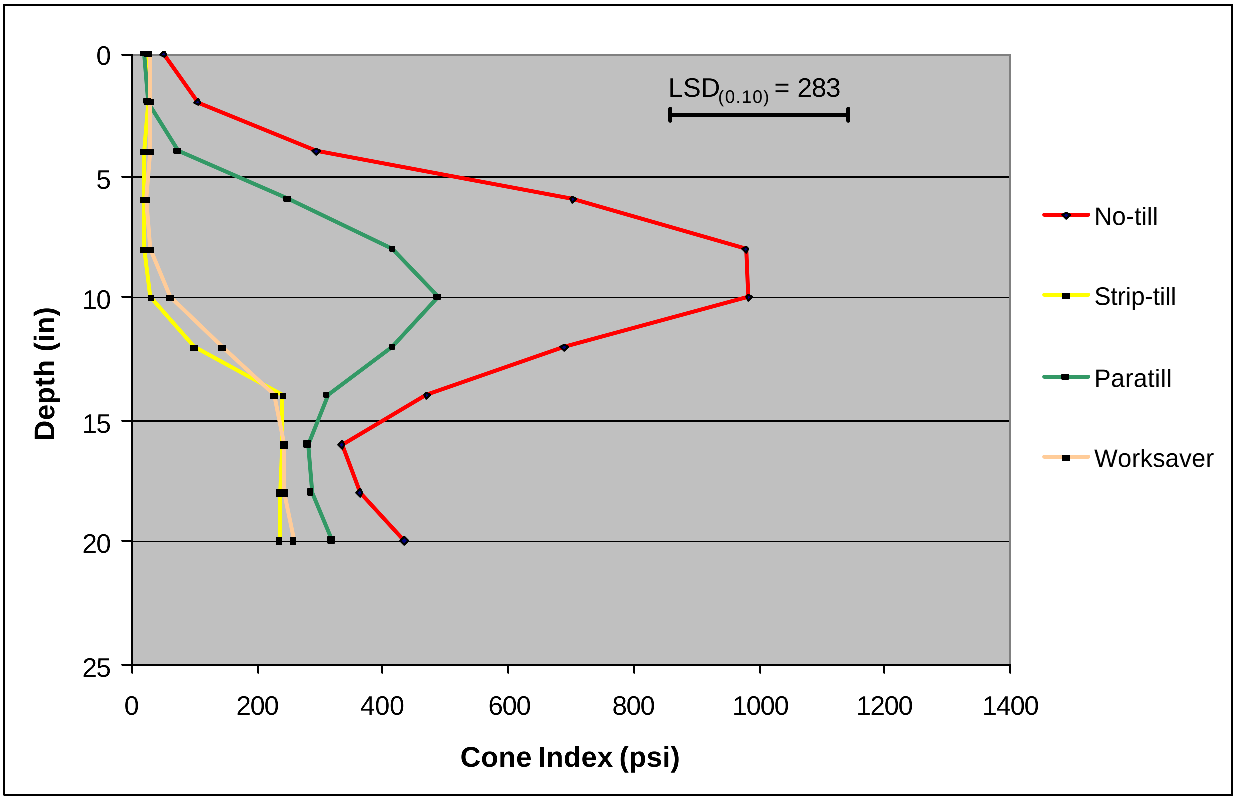

Figure 2. Soil cone index values at in-row position for peanuts in 2005.

Bulk density was affected by subsoiling treatment ($P<0.0002$), position ($P<0.0001$) and depth ($P<0.0001$). The overall means for no-till were significantly higher than any of the subsoiled treatments (table 3).

Table 3. Bulk density by subsoiling treatment

Subsoiling treatment	Bulk density, g cm^{-3}
No-Till	1.918a
Strip-Till	1.878b
Paratill	1.869b
Worksaver	1.863b
LSD(0.10)	0.015

Also, significant interactions between cover and treatment ($P <0.0951$) and treatment and depth ($P< 0.010$) were found. Due to its important effect on root growth, the in-row bulk density values that had a cover crop were investigated further (fig. 3). The no-till tillage treatment had the highest values of bulk density especially below depths of 5 in. The KMC strip-till had the minimum values of bulk density above 6 inches that could be attributed to its design of being a straight-leg subsoiler. The bent-leg subsoilers like the Paratill and the Worksaver were designed to cause minimal surface disturbance and may not disrupt the soil in the in-row position quite as effectively as the KMC strip-till.

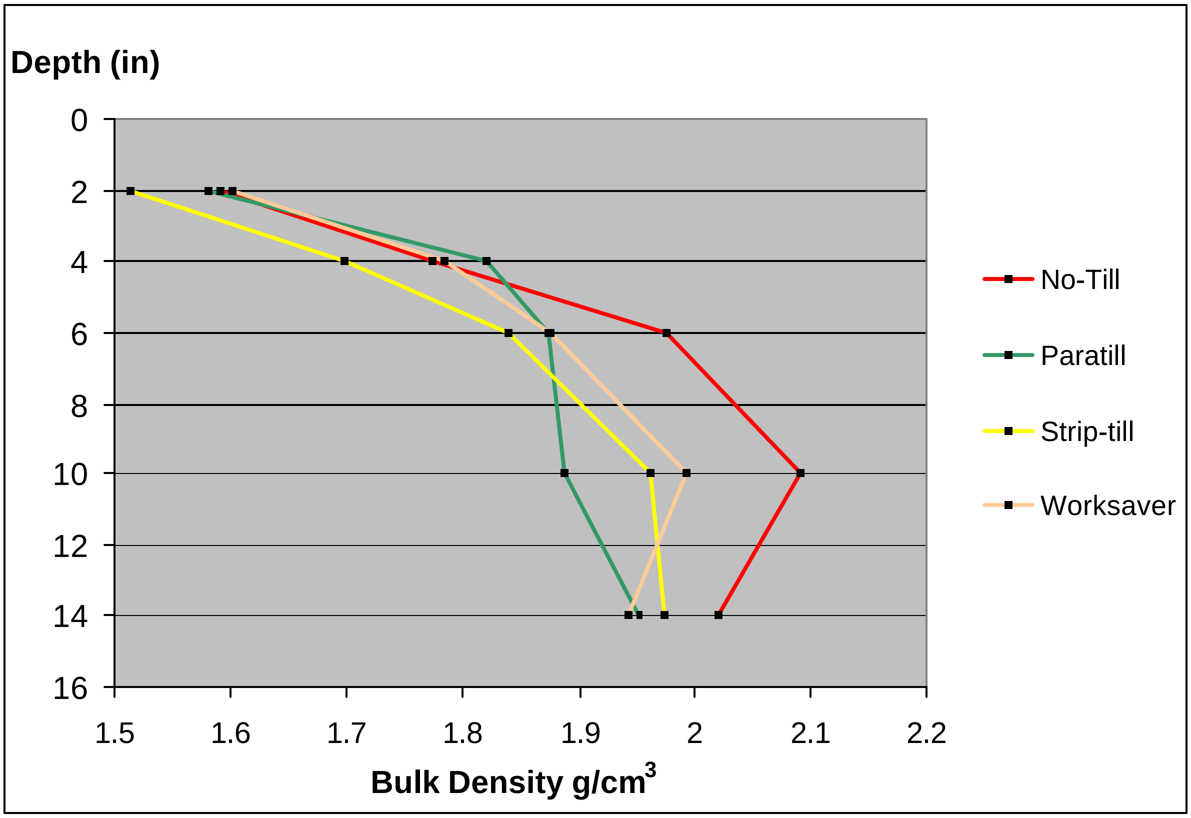

Figure 3. In-row bulk density with a cover crop as affected by subsoiling treatment.

Cotton Leaf Temperature

There was no statistical significance for cotton leaf temperature for subsoiling treatments. However, the cover crop had a positive effect in lowering leaf temperature as shown in table 4. This could be related to increased soil moisture provided by the cover crop that prevented plant stress and reduced leaf temperature (table 2).

Table 4. Cotton leaf temperature affected by cover crop.

Date	Cover °F	No-cover °F	LSD (0.10)
18-Jul	94.89	97.01	1.67
28-Jul	91.95	94.31	0.97
7-Aug	89.18	89.78	1.00 ns
17-Aug	85.74	87.63	0.55

Seed Cotton and Peanut Yield

Results showed that subsoiling treatments significantly increased yields for peanuts and cotton in 2004 ($P<0.001$), 2005 ($P<0.0003$) and 2006 ($P<0.0003$). Crop yields for no-till treatment were the lowest in every year but 2003 when no-till had the highest peanut production (although not significant). The 2003 peanut crop had abundant rain (fig. 4) from April to October where precipitation was approximately 37 in. (Optimal peanut production water requirements are normally approximately 20 to 30 in, Baker et al., 2000). Paratilling also produced the highest yields from 2004 to 2006 although they were not statistically different from the other in-row subsoiling treatments.

Table 5. Peanut and cotton seed yield by treatment.

Subsoiling Treatment	2003 Peanut	2004 Cotton	2005 Peanut	2006 Cotton
		lb ac^{-1}		
No-Till	4367a	1956b	1728b	1337c
Worksaver	4212a	2809a	2838a	1838b
Strip-till	3654a	2886a	2795a	2165ab
Paratill	3531a	2940a	3179a	2332a
LSD(0.10)	NS	295	478	329

The effect of the cover crop on crop yield was only significant for the 2006 cotton crop when a severe drought hit the Southeastern states and Alabama farmers suffered great losses. During 2006, in the period of April to October, the total precipitation was 19 in which is 28% below the minimum requirement for cotton (27.5 in; Brouwer, 1986). The cover crop significantly ($P<0.013$) increased cotton seed yield in 2006 with 2139 lb ac^{-1} versus 1900 lb ac^{-1} for rye cover and no-cover, respectively. The results suggest that cover crop benefits were especially important when water was the limiting factor. This conclusion concurred with results for soil moisture obtained in 2006 which indicated significantly increased volumetric water under a cover crop (table 2).

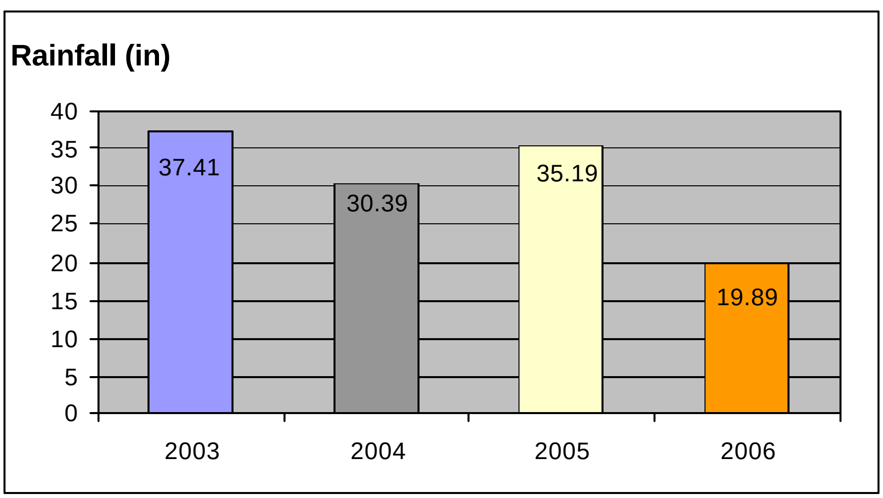

Figure 4. Cumulative precipitation at Wiregrass Research Station from April to October

CONCLUSIONS

1. In-row subsoiling was particularly effective in reducing soil compaction as measured by cone index values and bulk density. Consequently, cash and cover productivity were also increased by in-row subsoiling regardless of the implement model.

2. The cover crop increased volumetric water content and lowered cotton leaf temperature. During an especially dry year of 2006, the cover crop also was responsible increased soil moisture and for significantly increasing cotton yield.

3. We conclude that subsoiling is an indispensable practice for obtaining satisfactory productivity in southern Coastal Plain soils and should be coupled with a winter cover crop which can increase yield, especially during a summer drought.

REFERENCES

American Society of Agricultural Engineers. 1998. ASAE Standards, engineering, and data. ASAE Standard S313.2. ASAE, St. Joseph, MI.

Assouline, S. 2006. Modeling the relationship between soil bulk density and the water retention curve. Vadose Zone J. 5:554–563 (2006).

Baker, R.D., R.G. Taylor, and F. McAlister. 2000. Peanut Production Guide H-648. http://cahe.nmsu.edu/pubs/_h/h-648.html New Mexico State University, accessed 5/11/2007.

Brouwer, C**.** 1986. FAO Irrigation Water Management Training Manual No. 3 http://www.fao.org/docrep/S2022E/s2022e02.htm , accessed 5/1/2007.

Busscher, W.J., P.J. Bauer, D.W. Reeves, G.W. Langdale, and E.C. Burt**.** 1996. Minimum tillage cultivation in a hardpan soil**.** Proceedings of the 19th Annual Southern Conservation Tillage Conference for Sustainable Agriculture, Jackson, Tennessee.

CTIC. 2005. National crop residue management survey. Conservation Technology Information Center, West Lafayette, IN.

Ess, D. R., D. H. Vaughan, and J. V. Perumpral. 1998. Crop residue and root effects on soil compaction. Trans. ASAE 41(5): 1271-1275.

Khalilian, A., T.H. Garner, H.L. Musen, R.B. Dodd, and S.A. Hale. 1988. Energy for conservation tillage in Coastal Plain soils. Trans. ASAE 31(5):1333-1337.

Mapa, R.B., R.E. Green, and L. Santo. 1986. Temporal variability of soil hydraulic properties with wetting and drying subsequent to tillage. Soil Sci. Soc. Am. J. 50:1133–1138.

Pettigrew, W.T. 2004. Physiological Consequences of Moisture Deficit Stress in Cotton. Crop Sci. 44:1265–1272.

Raper, R.L. 2005. Agricultural traffic effects on soil. J. Terramechanics 42(3-4):259-280.

Raper, R. L., D. W. Reeves, C. H. Burmester, and E. B. Schwab. 2000a. Tillage depth, tillage timing, and cover crop effects on cotton yield, soil strength, and tillage energy requirements. Appl. Eng. Agric.16(4): 379-385.

Raper, R. L., D. W. Reeves, E. B. Schwab, and C. H. Burmester. 2000b. Reducing soil compaction of Tennessee Valley soils in conservation tillage systems. J. Cotton Sci. 4(2): 84-90.

Raper, R. L., D. W. Reeves, J.N. Shaw, E. van Santen, P.L. Mask. 2005. Using site-specific subsoiling to minimize draft and optimize corn yields. Trans ASAE. Vol. 48(6): 2047-2052.

Raper, R.L., B.H. Washington, and J.D. Jerrell. 1999. A tractor mounted multiple-probe soil cone penetrometer. Appl. Eng. Agric. 15(4):287–290.

Reeder, R.C., R.K.Wood, and C.L. Finck. 1993. Five subsoiler designs and their effects on soil properties and crop yields. Trans. ASAE 36(6):1525–1531.

Reeves, D. W. 1994. Cover crops and rotations. In Advances in Soil Science: Crops Residue Management, ed. J. L. Hatfield and B.A. Stewart, 125-172. Boca Raton, Fla.: Lewis Publishers.

SAS Institute. 1988. SAS/STAT User's Guide. Version 9.1. SAS Inst., Cary, NC.

Taylor, H. M. and H.R. Gardner. 1963. Penetration of cotton seedling taproots as influenced by bulk density, moisture content and strength of soil. Soil Sci. J. 96(3):153-156.