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Comparison of Five Tillage Systems in Coastal Plain Soils for Cotton Production

Ahmad Khalilian[1*], Michael A. Jones[2], Philip J. Bauer[3], Michael W. Marshall[4]

[1]Department of Agricultural Sciences, Clemson University, Clemson, SC, USA
[2]Department of Plant and Environmental Sciences, Clemson University, Clemson, SC, USA
[3]USDA-ARS, Florence, SC, USA
[4]Edisto Research and Education Center, Clemson University, Blackville, SC, USA
Email: *akhlln@clemson.edu, majones@clemson.edu, phil.bauer@ars.usda.gov, marsha3@clemson.edu

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Abstract

Soil compaction management in the southeastern USA typically relies heavily on the practice of annual deep tillage. Strip tillage systems have shown considerable promise for reducing energy and labor requirements, equipment costs, soil erosion, and cotton plant damage from blowing sand. Replicated field trials were conducted for three years in South Carolina, to compare the performance of three different strip tillage systems to conventional tillage and no-till methods. A second objective was to investigate whether the frequency of deep tillage can be reduced by planting cotton directly using controlled wheel traffic into the previous year's subsoiler furrow. Tillage treatments included: conventional tillage (disk-subsoil-bed), straight shank strip-till, bent-leg shank strip-till (Paratill), bent-leg shank strip till (Terra Max), and no-till. Deep tillage was performed in all plots the first year. In years two and three, the plots were split and half received annual deep tillage and the other half were not deep tilled either year. Tillage methods were compared side by side with and without irrigation. Deep tillage reduced soil compaction and increased taproot length and cotton yields than the no-till system. There was no difference in cotton lint yield between the strip-till systems and conventional tillage in either dry land or irrigated plots. Deep tillage increased cotton lint yields compared to no-till. There was no difference in lint yield between plots which were deep-tilled in all three years with those which had tillage operation only in first year of the test. Dry matter partitioning at first bloom was reduced in plant height, total dry weight, and leaf area in strip-till and no-till production systems compared to the conventional tillage system. The results suggest that all three strip tillage systems are equally effective for cotton production and that annual deep tillage is not necessary if controlled traffic is employed.

Keywords

Tillage, Cotton, Soil Compaction, Controlled Traffic, Irrigation

1. Introduction

Nationwide farmers across the U.S. lose over $1 billion in crop revenues every year due to the effects of soil compaction [1]. Reduction of losses due to soil compaction by one percent nationally could result in an additional $100 million in crop revenue. Soil compaction limits root penetration below the plowing depth and is a significant problem in many soils in the Southeastern U.S. It reduces yields and makes plants more susceptible to temporal drought stress. Most upland sandy soils of the coastal plains have a naturally occurring compacted zone called hardpan or the E-horizon [2] [3]. This zone occurs at a depth of 25 to 40 cm in the soil profile and ranges from 5 to 20 cm in thickness [2]. This layer must be disrupted with tillage so that roots can grow into lower soil horizons to acquire additional water and nutrients. Soil compaction management in this region relies heavily on the use of annual deep tillage, which improves yields [4] [5] [6].

Conventional cotton production systems in the Southeastern U.S. typically involve three to five field operations at a cost of approximately $90 per hectare [3]. In conventional tillage, production fields are disked two to three times to bury previous crop residue, control existing weeds, and incorporate soil residual herbicides, followed by subsoil and bedding to alleviate soil compaction zone and prepare seedbed; afterwards, the beds are knock over and then cotton is planted in the finished seedbed. The costs associated with conventional systems plus the advent of better over-the-top post-emergence herbicides and equipment have stimulated interest in conservation tillage, especially strip tillage, among many South Carolina cotton growers. Strip tillage systems have shown considerable promise for reducing energy and labor requirements, equipment costs, soil erosion, and cotton plant damage from blowing sand. Cost savings of approximately $50 per hectare could be achieved by strip tillage compared to the conventional methods.

Deep tillage on these soils can be accomplished with implements that have either straight or bent-leg shanks. Bent-leg implements, such as Paratill and Terra Max, are commercially available for crop production. Previous research in South Carolina has shown that bent-leg shanks loosened a greater volume of the compacted layer compared to the straight-legged shanks [5] [6]. Averaged over three years, non-irrigated soybeans planted behind a Paratill yielded 11% more than those planted following a straight shank subsoiler [5]. The average yield increase from irrigated locations was 8.6%. Deep tillage operation with a bent-leg shank plow (Paratill) resulted in soils with higher saturated hydraulic conductivity and lower bulk density in the plant root zone compared to soils under the conventional tillage system [7] [8].

There is a great interest in reducing the frequency of deep tillage to reduce horsepower requirements and fuel costs associated with tillage operations. Research in selected sandy soils in South Carolina has shown reconsolidation of the hardpan layer from one season to another [5]. The controlled-traffic system is designed to minimize hardpan development by isolating vehicle wheel traffic away from the crop root zone. Vehicle tires need a compact zone to support traffic in all-weather conditions; however, crop roots need a relatively loose and friable soil which enhances root penetration and access to soil moisture, oxygen, and nutrients. Previous research on controlled-traffic systems has shown that, under the right conditions controlled-traffic can increase crop yield, optimize vehicle tire flotation and traction for all-weather operations, and minimize the need for seasonal deep-tillage [5] [9] [10].

Therefore, research is needed to evaluate and compare the effects of bent-leg strip, straight shank strip, conventional, and no tillage systems on cotton production under irrigated and dryland regimes. The residual effects of these tillage methods under a controlled traffic scenario on cotton production also need to be determined.

2. Objectives

The objectives of this study were: 1) To evaluate the performance of three different strip tillage systems compared to conventional and no-till methods in terms of effects on soil parameters, crop growth and development, and tractor energy requirements; and 2) To investigate whether the frequency of deep tillage can be reduced by planting cotton directly into the previous year's subsoiler furrow using controlled traffic.

3. Methodology

3.1. Tillage Implements

Four units of the Unverferth strip attachment (Unverferth Manufacturing Co, Inc., Kalida, OH) were installed on a special toolbar which could be mounted behind 4-row tillage equipment (**Figure 1**). The toolbar was designed in a way that it could be easily moved from one tillage implement to another, using four U-bolts. Three different strip tillage systems were developed by mounting this attachment on a 4-row 1) Bingham Paratill (Bingham, Lubbock, TX); 2) Worksaver Terra Max (Worksaver, Inc., Litchfield, IL); and 3) KMC straight shank subsoiler (Kelley Manufacturing Co. Tifton, GA). For the conventional tillage plots, a 4-row KMC subsoiler-bedder was used to perform deep tillage and prepare seedbeds. The main difference between the Paratill and Terra Max bent-leg shanks is their physical shape. The Paratill shankis angled 45 degrees to the side, with respect to its vertical position, while the Terra Max shank is angled at 15 degrees. This results in different zone loosening patterns in the soil profile. Paratill typically loosens a zone of soil above the bottom of the shank about 66 cm

Figure 1. The Unverferth strip-till attachment mounted on a Worksaver Terra Max.

wide compared to 38 cm wide disrupted zone for the Terra Max.

3.2. Field Tests

Field studies were conducted for three years (2002-2004) at the Edisto Research & Education Center (Edisto REC), located in Barnwell County, SC. The soil type was Varina loamy sand (*Fine*, *kaolinitic*, *thermic Plinthic Paleudults*), a typical Coastal Plain soil. The experimental design was a split-plot design with main plots being tillage and subplots being subsoiling frequency, with four replications.

The main plots consisted of:

1) Conventional tillage (2 × disk + subsoil-bed + crop planting)

2) Straight shank strip-till system (KMC, 0 degree orientation to vertical)

3) Bent-leg shank strip-till system (Bingham Paratill, 45 degree orientation to vertical)

4) Bent-leg shank strip-till system (Worksaver Terra Max, 15 degree orientation to vertical)

5) No surface or deep tillage (no-till).

The subplots consisted of deep tillage every year or deep tillage during the first year only. Subplot size was four 1-m wide rows that were 30 m long. To determine the effects of irrigation on reconsolidation of the hardpan layer, identical experiments, one with and one without irrigation, were conducted adjacent to each other. However, in 2003 and 2004, sufficient precipitation occurred so that no irrigation events occurred in those years.

Cotton was planted and grown each year and managed according to recommended Extension practices for seeding, fertilization, insect, and weed control. Tillage operations were done in early May each year. Cotton variety DP 458 BG/RR (Delta Pine and Land Co., St. Louis, MO) was planted on May 8th in 2002. Cotton variety DP 555BG/RR (Delta Pine and Land Co., St. Louis, MO) was planted on May 7th, 2003 and May 14th, 2004, respectively. These two cotton varieties contained in-seed protection against bollworm (*Helicoverpa zea*) damage (Bollgard [BG]) and tolerance to topical applications of glyphosate herbicide (Roundup Ready [RR]). All plots were planted using a 4-row John Deere Max-Emerge 2 planter (John Deere Co., Moline, IL).

Soil compaction was measured in each plot to a depth of 46 cm using a microcomputer-based, tractor-mounted, recording penetrometer [3]. Soil compaction data were collected before the deep tillage operation and 6-weeks after planting. Soil compaction values were calculated from the measured force required to push a 30-degree cone with a 3.23 cm^2 base area into the soil.

Cotton height, taproot length, root dry weight, seedling population, total dry weight, leaf area index were collected during the growing season, around first bloom. Yield was collected around mid-October every year, using a cotton spindle picker equipped with sacking attachment and weighing system. Seed cotton samples were collected from each plot and ginned (seeds and plant residue removed) to determine percent lint content.

An instrumented John Deere tractor [11] was used to collect in field measurements of tractor fuel consumption, ground speed, wheel slip, and draft requirements of different tillage treatments. The statistical analysis was conducted using the SAS software (Version: 9.4; SAS Institute Inc., Cary, NC, USA). F-values from analysis of variance were considered significant at a probability level of 0.05. When sources of variation were significant, means were separated by calculating a least significant difference (LSD).

4. Results

4.1. 2002

Figure 2 shows profiles of in-row cone index versus depth from soil surface, for different tillage treatments at six weeks after planting in 2002. Cone index for the no-till treatment at this time clearly shows that the field had a hardpan in the E horizon at a depth of 13 to 30 cm. The limiting cone index value which prevents cotton root development is 2.07 MPa [12]. All deep tillage operations reduced soil compaction compared to no-till. Cone index values for all deep tillage systems were below the limiting value of 2.07 MPa throughout the tillage depth (38 cm). Strip till systems utilizing Paratill and Terra Max shanks reduced soil compaction in the non-traffic row-middles more than the straight shank subsoiler did (**Figure 3**). This was caused by the bent-leg orientation of shanks disturbing a wider section of the soil profile than the straight shank.

Cotton taproots measured six weeks after planting were longer in all plots receiving subsoiling than in the no-till plots. This occurred in both the irrigated and the dry land experiments (**Table 1**). Similar results were obtained with total root dry weight. Irrigation increased plant height and root dry weight by18% and 22%, respectively, compared to dry land.

No differences in plant stand were observed among the tillage treatments, with all plots ranging between 12 and 16 plants/m^2. First bloom dry matter

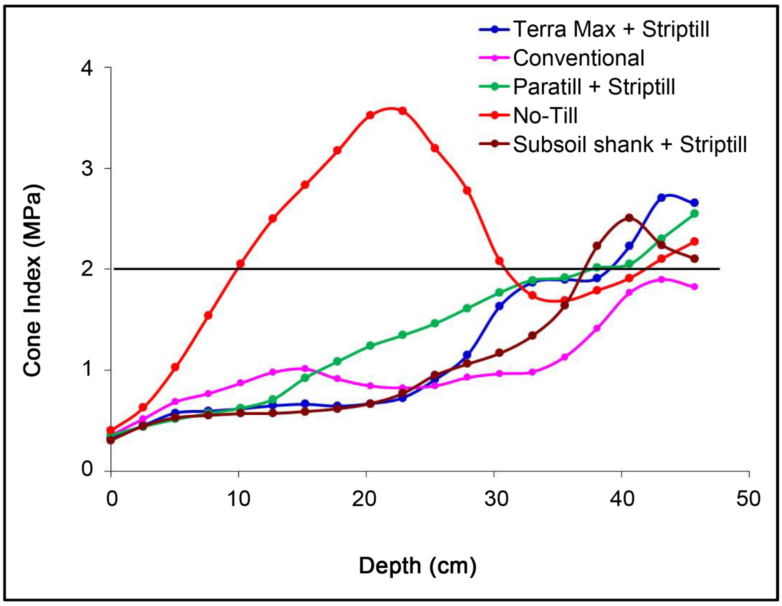

Figure 2. Effects of tillage on soil compaction from crop in-rows six weeks after planting, Edisto REC, 2002.

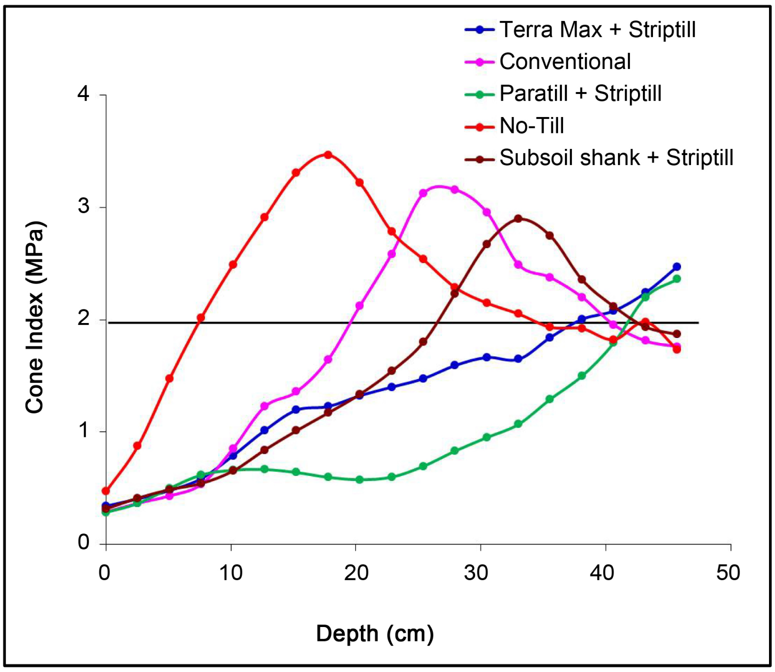

Figure 3. Effects of tillage on soil compaction from non-traffic row-middles (23 cm from crop rows) six weeks after planting, Edisto REC, 2002.

partitioning data showed a reduction in the growth and development of cotton grown in strip-till and no-till production systems compared to the conventional system. Total plant dry weight was reduced 19% to 43%, stem dry weight was reduced 21% to 47%, leaf dry weight was reduced 18% to 38%, and leaf area index was reduced 19% to 37% at first bloom. Reproductive development was also affected by tillage system. Plants grown with conventional tillage had more

Table 1. Effects of tillage and irrigation on cotton height, taproot length, and root weight six weeks after planting, Edisto REC, 2002.

Water Regime	Tillage Treatments	Cotton Plant Height (cm)	 Taproot length (cm)	 Root Dry weight (g)
Irrigated	Conventional Tillage	99 a*	40 a	32.8 a
	Straight Shank Strip-till	109 a	40 a	35.5 a
	Paratill, Bent-leg Shank Strip-till	104 a	40 a	33.9 a
	Terra Max, Bent-leg Strip-till	99 a	39 a	32.8 a
	No-Till	71 b	18 b	25.4 b
Dry Land	Conventional Tillage	88 a	34 a	30.1 a
	Straight Shank Strip-till	85 a	34 a	28.6 a
	Paratill, Bent-leg Shank Strip-till	83 a	35 a	28.3 a
	Terra Max, Bent-leg Strip-till	85 a	35 a	28.1 a
	No-Till	71 b	14 b	14.8 b

*Values in a column, within a water regime, followed with the same letter are not significantly different (LSD, $\alpha = 0.05$).

squares (17% to 38%) and partitioned more of their dry weight into squares compared to plants grown in strip-till or no-till systems. However, these differences in early-season growth and development did not result in differences in yield. Tillage systems had no effect on fiber quality in 2002 (Table 2).

There was no difference in cotton lint yield between the strip-till systems and conventional tillage in either dry land or irrigated plots in 2002 (Figure 4). However, deep tillage systems (conventional and strip-till) increased cotton lint yields compared to no-till production system. Cotton lint yields increased an average of 15% and 28% for irrigated and dry land plots, respectively. Also, irrigation increased cotton lint yields compared to dry land. Averaged across treatments, irrigated plots yielded 77% more than the dry land. Total precipitation during the 2002 growing season, was about 28 cm; therefore, 24 cm of supplemental water was applied to irrigated plots. Previous experiments conducted in South Carolina [13] found strong correlations between the depths of seasonal irrigation and seed cotton yields. In those experiments, maximum yield for all cotton cultivars was obtained when around 52 cm total water was applied (irrigation plus rain).

4.2. 2003

Figure 5 shows penetrometer data collected from the cotton rows six weeks after planting in 2003. There was no difference in soil compaction between the plots which had deep tillage operation only in 2002 and those which had deep tillage operations in 2002 & 2003. However, averaged throughout the tillage depth (38 cm), annual deep tillage operation reduced cone index values by 9% in crop rows

Table 2. Gin turnout and fiber quality parameters in response to various tillage systems.

Treatments	Gin Turnout (%)	Micronaire	Length (cm)	Strength (g/tex)	Uniformity	Elongation
Conventional	39.8 a*	5.1 a	2.69 a	29.6 a	81.3 b	8.3 a
Straight Shank	39.8 a	5.0 a	2.74 a	30.1 a	81.9 b	8.6 a
Paratill	39.6 a	5.2 a	2.64 a	28.9 a	81.6 b	8.4 a
Terra Max	39.0 a	5.2 a	2.64 a	28.7 a	81.4 b	8.2 a
No-Till	40.9 a	5.1 a	2.72 a	30.6 a	82.8 a	8.5 a

*Values in a column, followed with the same letter are not significantly different (LSD, $\alpha = 0.05$).

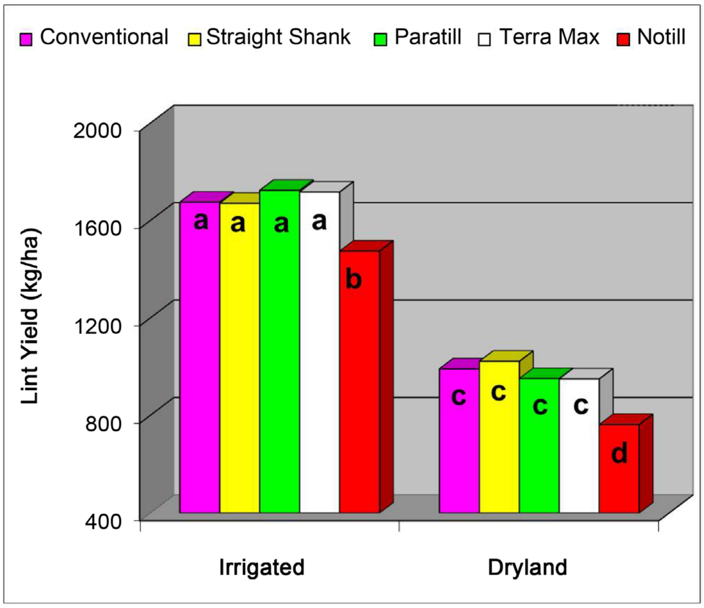

Figure 4. Effects of tillage systems on cotton lint yield (Edisto REC, 2002). Yield values followed with the same letter are not significantly different (LSD, $\alpha = 0.05$).

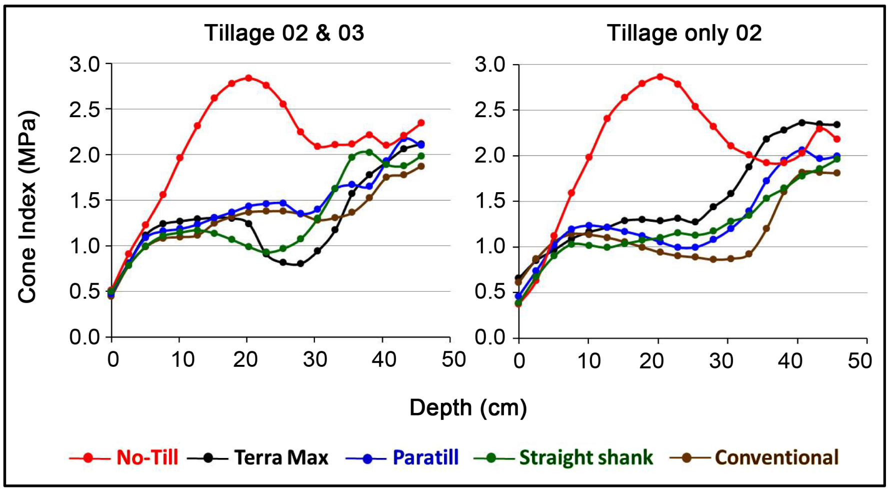

Figure 5. Effects of tillage on in-row soil compaction six weeks after planting (Edisto REC, 2003).

compared to deep tillage only in 2002.

In 2003, we had about 75 cm of rain during growing season compared to average rainfall of 51 cm for the same period. Therefore, irrigation was not applied to "irrigated" plots at the Edisto REC. Since there was no difference in lint yield between dry land and irrigated plots the yield data were averaged over 8 replications. There was no difference in lint yield between cotton planted back into the previous year's subsoil furrows compared to an annual deep tillage operation (**Figure 6**). Due to high amount precipitation in 2003, cotton yield on all plots were higher than the average yield for the test field during normal years. Also statistically there were no differences in yield among the deep tillage plots. However, deep tillage increased lint yield compared to no-till plots. The average yield increase was 41.5%. Again, tillage systems had no effect on fiber quality in 2003 (**Table 3**). Also, there was no difference in fiber quality between cotton planted back into the previous year's subsoil furrows compared to an annual deep tillage operation.

Cotton taproots measured six weeks after planting were longer in all plots receiving subsoiling than in the no-till plots. This occurred in both experiments, which received tillage operations either in 2002 only or in both 2002 and 2003. Similar results were obtained with total root dry weight for plots, which was tilled only in 2002 (**Table 4**). However, for plots, which were tilled every year, total root dry weight were higher for the Paratill and Terra Max strip-till systems than the convention and straight-shank strip-till tillage systems. This was caused by the bent-leg orientation of shanks disturbing a wider section of the soil profile than the straight shanks. Total root dry weight in annual tillage plots was 25% higher than plot which had tillage operations only in 2002. Although not statistically different, annual deep tillage increased taproot length by 6%.

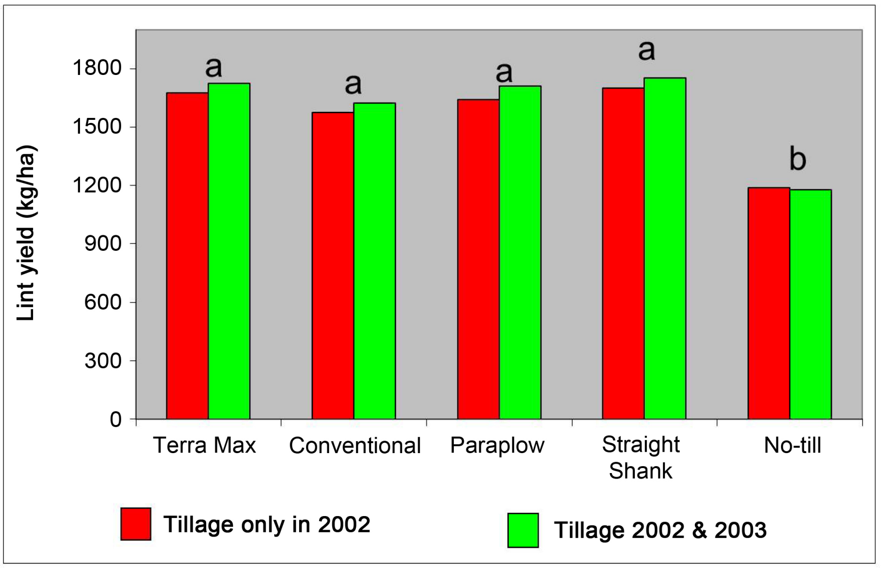

Figure 6. Residual effects of deep tillage on lint yields, Edisto REC, 2003. Yield values followed with the same letter are not significantly different (LSD, $\alpha = 0.05$).

Table 3. Effects of tillage system and tillage frequency on cotton fiber quality (2003).

Tillage Frequency	Treatments	Micronaire	Length (cm)	Strength (g/tex)	Uniformity	Elongation
Tillage in 2002 only	Conventional	4.3 a	2.77 a	27.3 a	82.7a	8.4 a
	Straight Shank	4.3 a	2.78 a	27.3 a	81.8 a	8.5 a
	Paratill	4.6 a	2.74 a	26.8 a	81.7a	8.3 a
	Terra Max	4.4 a	2.77 a	27.2 a	80.8a	8.3 a
	No-Till	4.4 a	2.71 a	26.4 a	80.8 a	8.3 a
Tillage in both 2002 and 2003	Conventional	4.4 a	2.77 a	27.6 a	81.9 b	8.3 a
	Straight Shank	4.3 a	2.73 a	27.1 a	81.3 b	8.0 a
	Paratill	4.4 a	2.78 a	27.9 a	82.1 b	8.0 a
	Terra Max	4.3 a	2.76 a	28.0 a	82.2 b	8.2 a
	No-Till	4.5 a	2.74 a	27.5 a	80.7 a	8.2 a

*Values in a column, within a tillage frequency, followed with the same letter are not significantly different (LSD, $\alpha = 0.05$).

Table 4. Effects of tillage frequency on cotton taproot length and total root dry weight, six weeks after planting (2003).

Treatments	Tillage Frequency			
	Tillage in 2002 only		Tillage in both 2002 and 2003	
	Length (cm)	Weight (g)	Length (cm)	Weight (g)
Conventional	38.9 a	22.7 a	41.6 a	26.5 b
Straight Shank	38.4 a	21.7 a	40.2 a	27.2 b
Paratill	39.2 a	25.9 a	41.0 a	33.9 a
Terra Max	38.8 a	25.9 a	40.3 a	32.7 a
No-Till	18.6 b	14.1 b	19.9 b	8.3 c

*Values in a column, followed with the same letter are not significantly different (LSD, $\alpha = 0.05$).

4.3. 2004

Figure 7 shows residual effects of deep tillage on soil penetrometer data, collected from the cotton rows six weeks after planting in 2004. Annual deep tillage operations, reduced soil cone index values in the E-horizon layer. However, average cone index values for the deep tillage operations in only 2003, still were below the limiting value of 2.07 MPa throughout the tillage depth (38 cm).On average, annual deep tillage operation reduced cone index values by 20% in crop rows compared to deep tillage only in 2002 (deep tillage operation every three years).

Figure 8 shows residual effects of deep tillage on lint yields for 2004. Statistically there was no difference in lint yield between tillage every three years compared to annual deep tillage operation. Therefore, with controlled traffic and planting directly into the previous year's subsoiler furrow, the residual effect of deep tillage operations could extend for one or two additional years in coastal plain soils. However, annual tillage numerically increased cotton yield by about

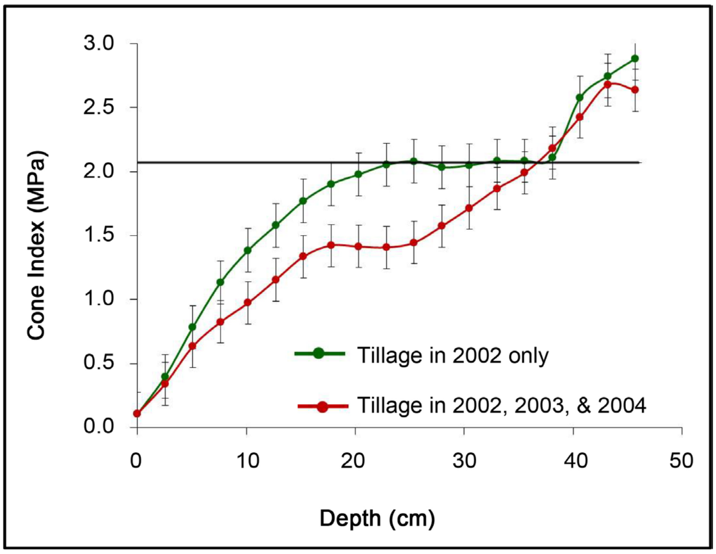

Figure 7. Effects of tillage frequency on average in-row soil compaction values, measured six weeks after planting (Edisto REC, 2004).

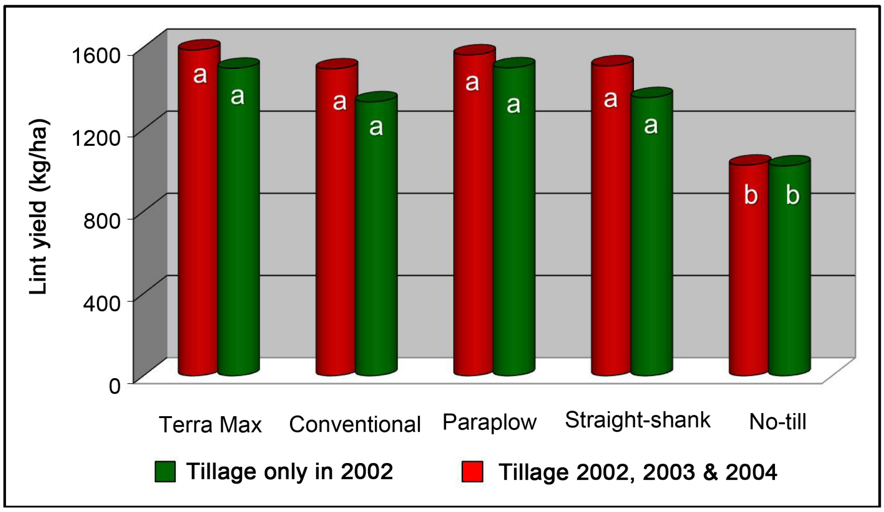

Figure 8. Residual effects of deep tillage on lint yields, Edisto REC, 2004. Yield values followed with the same letter are not significantly different (LSD, $\alpha = 0.05$).

100 kg/ha compared to tillage every three years. This is due to the lower soil compaction values (20% lower) in the crop rows for the annual tillage treatments. In 2004, we had about 61 cm of rain during growing season (10 cm above the average rainfall). Therefore, irrigation was not applied to "irrigated" plots at the Edisto REC. Since there was no difference in lint yield between dry land and irrigated plots the yield data were averaged over 8 replications. Again, deep tillage increased lint yield compared to no-till plots. The average yield increase was 45%.

An instrumented John Deere tractor was used to make in field measurements of tractor fuel consumption, ground speed, wheel slip, and draft requirements of different tillage treatments. All energy measurements were collected at 7.6 km/h ground speed and 38-cm tillage depth. Figure 9 shows tillage implements power requirements for three strip-till (Terra Max, Paratill, and Straight shank) systems, on three different soil types. Statistically there were no differences in energy requirements of these tillage equipment on a given soil type.

Similar to 2003 results, cotton taproots measured six weeks after planting were longer in all plots receiving subsoiling (subsoiled either only in 2002 or in every year) than in the no-till plots. Similar results were obtained with total root dry weight for plots which were tilled only in 2002 (Table 5). However, for plots which were tilled every year (2002, 2003, and 2004), total root dry weight were higher for the Paratill and Terra Max strip-till systems than the convention and straight-shank strip-till tillage systems. This was caused by the bent-leg orientation of shanks disturbing a wider section of the soil profile than the straight shanks. On average, annual deep tillage increased taproot length by 17% over no-till.

5. Conclusion

Deep tillage systems reduced soil compaction and increased taproots length and

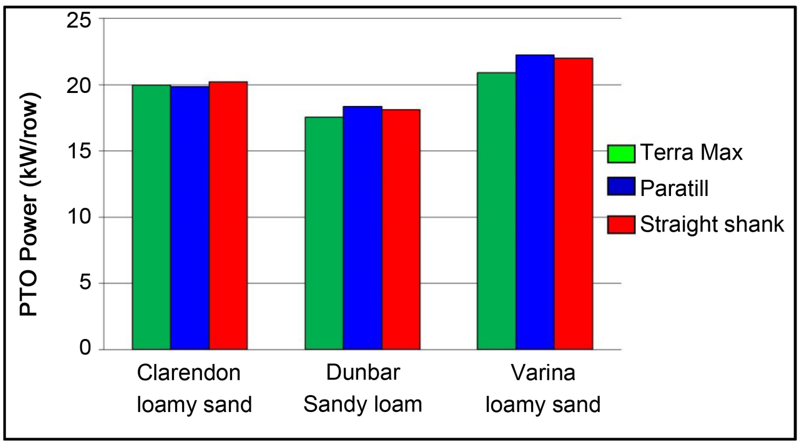

Figure 9. Equivalent tractor Power-Take-Off (PTO) power needed for different tillage implements (kW/row).

Table 5. Effects of tillage frequency on cotton taproot length and total root dry weight, six weeks after planting (2004).

Treatments	Tillage Frequency			
	Tillage in 2002 only		Tillage in 2002, 2003, and 2004	
	Length (cm)	Weight (g)	Length (cm)	Weight (g)
Conventional	37.6 a	33.1 a	42.9 a	32.2 b
Straight Shank	37.2 a	34.9 a	42.7 a	32.8 b
Paratill	37.9 a	34.6 a	44.1 a	39.8 a
Terra Max	37.5 a	32.3 a	43.5 a	39.1 a
No-Till	17.3 b	25.1 b	20.4 b	25.2 c

*Values in a column, followed with the same letter are not significantly different (LSD, $\alpha = 0.05$).

cotton yields compared to no-till system. There was no difference in cotton yield between the strip-till systems and conventional tillage in either dry land or irrigated plots. Deep tillage increased lint yields compared to no-till. Averaged over all treatments, irrigation increased lint yields by 77% compared to dry land in a dry year (2002). There was no difference in lint yield between plots which had deep tillage operation in all three years with those which had tillage operation only in first year of the test. Therefore, with controlled traffic and planting directly into the previous year's subsoiler furrow, the residual effect of deep tillage operations could extend for one or two additional years in coastal plain soils without causing farmers a loss of crop yield. Dry matter partitioning data collected at first bloom showed a reduction in the growth and development of plants grown in strip-till and no-till production systems compared to the conventional system.

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