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# Tillage systems for a cotton–peanut rotation with winter-annual grazing: Impacts on soil carbon, nitrogen and physical properties

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**Abstract**

Integrating livestock with cotton (*Gossypium hirsutum* L.) and peanut (*Arachis hypogaea* L.) production systems by grazing winter-annuals can offer additional income for producers provided it does not result in yield-limiting soil compaction. We conducted a 3-year field study on a Dothan loamy sand (fine-loamy, kaolinitic, thermic plinthic kandiudults) in southern Alabama, USA to determine the influence of tillage system prior to cotton–peanut planting on soil properties following winter-annual grazing. Two winter-annual forages [oat (*Avena sativa* L.) and annual ryegrass (*Lolium mutiflorum* L.)] and four tillage practices [chisel + disk, non-inversion deep tillage (paratill) with and without disking and no-till] were evaluated in a strip-plot design of four replications. We evaluated cone index, bulk density, infiltration, soil organic carbon (SOC), and total nitrogen (N). Paratilling prior to cotton or peanut planting, especially without surface soil tillage, reduced compaction initially to 40 cm and residually to 30 cm through the grazing period in winter. There were no significant differences in cone index, bulk density, or infiltration between forage species. No-tillage resulted in the greatest bulk density (1.65 Mg $m^{-3}$) and lowest infiltration (36% of water applied), while paratilling increased infiltration in no-tillage to 83%. After 3 years, paratilling increased SOC 38% and N 56% near the soil surface (0–5 cm), as compared to concentrations at the beginning of the experiment, suggesting an improvement in soil quality. For coastal plain soils, integrating winter-annual grazing in a cotton–peanut rotation using a conservation tillage system of non-inversion deep tillage (paratill) with no surface tillage can improve soil quality by reducing cone index, increasing infiltration, and increasing SOC in the soil surface.
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## 1. Introduction

Soils of the southern United States have undergone degradation processes, which are reflected in low SOC contents (Hunt et al., 1995). After decades of conventional tillage (typically moldboard and chisel plowing, followed by disking and leveling with a cultivator), millions of hectares of cropland in the region are degraded, often producing below their economic potential and resulting in more difficult management decisions. Additionally, areas cropped with low residue-producing plants (e.g., cotton or peanut) are especially susceptible to soil erosion and

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reduced SOC due to small amounts of residue returned to the soil.

Conservation tillage, cropping intensification, and inclusion of sod-based rotations have been recognized for maintaining or increasing SOC and improving soil physical conditions (Varvel, 1994; Reeves, 1997; Lal et al., 1998; Franzluebbers et al., 2000). These improved conditions control several key functions (i.e., gas and water exchange, nutrient recycling, erodibility) that are important to biological processes and environmental quality.

Annual sod-based rotations with row crops not only can offer reduced economic risks for producers but also could increase SOC, which improves soil quality and productivity. However, winter-annual grazing may result in excessive soil compaction, which can severely limit yields of double-cropped cash crops (Touchton et al., 1989; Mullins and Burmester, 1997). Cattle can exert pressures up to 0.2 MPa, which is significantly greater than the pressure exerted on the soil surface by tractors, which can vary from 0.03 to 0.15 MPa (Proffitt et al., 1993). Daniel et al. (2002) showed that grazing activity (e.g., trampling, defoliation, defecation, and urination) can detrimentally affect soil properties by degrading soil structure, increasing soil bulk density, and reducing water infiltration rates. Livestock treading can be detrimental to soil structure by causing compaction, which adversely influences air, water, and nutrient movement and chemical and biological processes in soils (Greenwood and McKenzie, 2001). Limited and excessive water or oxygen deficiency can restrict root proliferation and nutrient absorption.

Winter grazing in the southern USA occurs under conditions when precipitation exceeds evapotranspiration and soils are most vulnerable to compactive forces (Greenwood and McKenzie, 2001). Under these conditions, grazing could increase soil bulk density, penetration resistance, and decrease porosity (Warren et al., 1986; Proffitt et al., 1993; Greenwood and McKenzie, 2001).

Several studies have revealed that cotton and peanut are especially vulnerable to soil compaction (Hartzog and Adams, 1989; Burmester et al., 1993; Reeves and Mullins, 1995; Jordan et al., 2001). While non-inversion deep tillage at planting has been frequently used to alleviate soil compaction for cotton and peanut grown on sandy Coastal Plain soils, tillage requirements for cotton and peanut following winter-annual grazing have not been studied or developed. Additionally, little is known concerning the direct impact of short-term grazing on soil properties in the Coastal Plain.

The objective of this study was to determine the influence of tillage system prior to cotton–peanut planting on soil properties following winter-annual grazing of two forages in the Coastal Plain of the southern USA. Our goal was to establish an optimal choice of forage and tillage system to mitigate the impact of grazing on soil properties and maintain crop yields.

## 2. Materials and methods

### 2.1. Site description

The experiment was initiated in October 2000 and conducted for 3 years at the Alabama Agricultural Experiment Station's Wiregrass Research and Extension Center (31°24'N, 85°15'W) in the Coastal Plain of southeastern Alabama, USA. Soil at this location is a well-drained Dothan loamy sand and has a 0.04–0.1 m thick tillage or traffic pan 0.2–0.35 m below the soil surface. The location had been cropped previously with conventional tillage (moldboard plowing, disking and leveling with a field cultivator) in a cotton–peanut rotation managed according to recommendations of the Alabama Cooperative Extension System (ACES, 2006). The climate for this area is humid subtropical, with a mean annual air temperature of 18 °C and 1400 mm annual precipitation.

### 2.2. Cultural practices

Winter-annual forages and summer tillage practices were evaluated in a strip-plot design with four replications (Gomez and Gomez, 1984). Two winter-annual forages (oat and annual ryegrass) served as horizontal treatments (main plot) and four tillage practices served as vertical treatments (subplots). In this design, horizontal plots (forage species) were randomized in 100 m × 61 m strips horizontally within each replication. The 15.2 m × 7.3 m vertical plots (spring tillage for peanut and cotton) were assigned randomly and arranged vertically or perpendicular to the forage plots within each replication. At the beginning of the experiment (October 2000) all plots were disked and seeded with oat or ryegrass with a no-till drill (Great Plains Mfg. Inc., Salina, KA).[2] On October 2001 and 2002 the plots were planted with oat

[2] Reference to trade or company name is for specific information only and does not imply approval or recommendation of the company by the USDA or Auburn University to the exclusion of others that may be suitable.

or ryegrass without tillage operation using the same no-till drill used in the beginning of the experiment (2000). Phosphorus, K, and lime applications for forages, peanut, and cotton were based on Alabama Cooperative Extension System soil test recommendations (Adams and Mitchell, 2000). All winter-annual forages were killed prior to summer tillage with application of 0.9 kg a.i. $ha^{-1}$ glyphosate approximately 4–6 weeks before cotton and peanut planting in May in all years.

Yearling steers (initial weight = 260 kg averaged over years) were stocked at a density of 5 head $ha^{-1}$ on the experimental area in middle of January and removed in early April. Steers continuously grazed the winter-annual forages (oat or ryegrass, depending on forage treatment) for 70, 84, and 89 d in 2001, 2002, and 2003, respectively. During each summer, the experimental area was alternately cropped with peanut and cotton. Tillage plots within these areas were 15.2 m long and 7.3 m wide with eight, 0.92 m rows. Tillage treatments were imposed in mid-April each year, within 10–20 days (dependent on weather) following termination of the winter-annual forages with glyphosate. The four summer tillage systems after both winter forages were: (1) chisel plowing to a depth of 20 cm + disk/level (10–15 cm depth); (2) under-the-row subsoiling with a bent-leg subsoiler equipped with a smooth roller following the shanks (Paratill®(see footnote 2), Bigham Brothers, Inc., Lubbock, TX) to a depth of 45–50 cm + disk/level; (3) paratill + no-tillage (i.e., no surface soil disruption) and (4) no-tillage (direct seeding with a no-till planter). Disk/leveling consisted of a pass with a tined cultivator and leveling board to break clods and level the soil surface following disking. The paratill equipped with the roller allowed non-inversion disruption of soil, with only a narrow (10 cm wide) zone of surface soil disturbance. The tractor used for tillage and planting operations was guided with a (see footnote 2) Trimble AgGPS® Autopilot automatic steering system (Trimble, Sunnyvale, CA), with centimeter-level precision. This enabled controlled traffic patterns for all summer crop operations during the 3-year study. Cotton and peanut were seeded 25 May, 24 May and 30 April on 2001, 2002, and 2003, respectively. In 2002, peanut plants were inverted at maturity and harvested, leaving the soil disturbed after harvest. The disturbed area was leveled with shallow field cultivation to a depth of 10–15 cm before forage planting in 2002. Peanut plants were inverted at maturity (9 October 2001, 4 October 2002, and 5 September 2003) and harvested (12 October 2001, 8 October 2002, and 9 September 2003) from the center two rows of each plot. For cotton evaluation, the center two rows were harvested with a spindle picker equipped with a sacking unit for determination of seed cotton yields on 23 October, 9 October, and 3 October for 2001, 2002, and 2003, respectively.

### 2.3. Determination of cone index and bulk density

Cone index (ASAE, 1999) was determined using a RIMIK CP 20 Cone Penetrometer (Agridry Rimik Pty Ltd., (see footnote 2) Toowoomba, Queensland, Australia) in 2002, 1 year following imposition of grazing-forage and summer tillage treatments for cotton. Cone index measurements were taken three times within horizontal treatments of winter forages (oat and ryegrass); before grazing on 20 January, after grazing on 12 April, and after summer tillage on 28 July. Measurements were made in three row positions: (1) in the row; (2) in the untrafficked interrow middle (45 cm from the row); (3) in the wheel-trafficked interrow middle (45 cm from the row). Five insertions were made at each position in the middle of plots in both forages. A penetrometer cone with a base area of 127 $mm^2$ was inserted to a depth of 40 cm on 20 January and to a depth of 50 cm for the other dates (2 cm increments for all measurements).

Measurements were taken when soil water content was close to field capacity. Average volumetric water content in the top 20 cm of soil was determined when cone index measurements were taken. These determinations were performed at the in-row position and in the untrafficked and trafficked interrows of each plot. A Tektronix 1502C (Tektronix Inc.(see footnote 2), Beaverton, OR) cable tester was used to measure soil water content by time-domain reflectrometry (TDR). Average soil water contents were 0.180, 0.185, and 0.175 $m^3\ m^{-3}$ on 20 January, 12 April, and 28 July, respectively. Soil water content at field capacity for this well-drained sandy loam is 0.209 $m^3\ m^{-3}$ in the 30 cm depth (Quisenberry et al., 1987).

In June 2003, 30 days after summer tillage operations for planting, a tractor-mounted, hydraulically driven, soil cone penetrometer was used to measure cone index (Raper et al., 1999). These measurements were taken during the last cropping season of the experiment in order to determine the cumulative impact of treatments. The specially designed tractor-mounted cone penetrometer enabled measurements to be taken in five positions simultaneously: (1) in the row; (2) 22.5 cm from the row in the untrafficked interrow; (3) 45 cm from the row in the untrafficked interrow; (4) 22.5 cm from the row in the wheel-trafficked interrow; (5) 45 cm from the

row in the wheel-trafficked interrow. Three insertions of the multiple-probe soil cone penetrometer were made in each plot. A penetrometer cone with a base area of 323 $mm^2$ was used to a depth of 50 cm and measurements were averaged every 5 cm (ASAE, 1999). We also measured soil water content from the 0 cm to 12 cm depth from the same plots as soil penetrometer measurements. It was physically impractical to incrementally sample soil water content to the 50 cm depth to correspond to penetrometer measurements. However, soil water content measured to the 12 cm depth provided some additional information regarding the impact of potential variations in soil water content on cone index. Samples were oven-dried at 105 °C for 72 h. Soil water content was expressed on a v/v basis, calculated from gravimetric water content and bulk density values. Average soil water content was 0.139 $m^3\ m^{-3}$ for the 0–12 cm depth, and no differences were found among forage and tillage systems on soil water content.

Contour graphs from the untrafficked interrows across the row to the wheel-trafficked interrows were then developed from cone index data using Surfer® for Windows (Golden Software Inc., Golden, CO). These contour graphs illustrate possible root-impeding layers of compaction present in the soil profile.

In June 2003 a tractor-mounted, hydraulically driven, soil core sampler (5.3 cm diameter) was used to determine soil bulk density. Undisturbed soil cores were dried in a forced air oven for 72 h at 105 °C. Six samples were taken in three row positions: (1) in the row; (2) in the untrafficked interrow middle (45 cm from the row); (3) in the wheel-trafficked interrow middle (45 cm from the row). Cores were separated and bulk density calculated for five depths (0–5 cm, 5–10 cm, 10–15 cm, 15–20 cm, and 20–25 cm).

### 2.4. Infiltration

Soil water infiltration was determined in the presence of residue cover at the end of the experiment (October 2003, following harvest of the 2nd cotton crop in the cotton–peanut–cotton cropping sequence) using a Cornell sprinkle infiltrometer described by Ogden et al. (1997). This device consisted of a portable sprinkler head placed onto a single inner infiltration ring (24.1 cm diameter). The ring was inserted to a depth of 7 cm where the lower edge of the round overflow hole was located. The overflowing water was collected and runoff calculated. Water was applied at a rate of $25 \pm 5$ mm $h^{-1}$ for ~30 min and runoff was determined at intervals of 3 min. Infiltration rates were determined by the difference between the application rate and runoff rate. Four determinations per plot were performed 22.5 cm from the row in the untrafficked interrow.

### 2.5. Soil organic carbon and total nitrogen content

Samples for SOC and N were collected at the beginning of the experiment (October 2000) and at the end of the experiment (September 2003, following the cotton–peanut–cotton cropping sequence).Twenty sampling points (3 cm diameter) were composited at four depths (0–5 cm, 5–10 cm, 10–15 cm, and 15–20 cm) at the beginning of the experiment in each replication. At the end of the experiment (2003), tillage systems following both forage species after the cotton–peanut–cotton cropping sequence were sampled in the same way as 2000, to determine changes in SOC and total nitrogen at the same depth as initially sampled. Samples were air-dried and ground to pass a 2 mm screen. Soil organic C and total nitrogen were determined by dry combustion (Yeomans and Bremner, 1991) using a [1]LECO CN-2000 analyzer (Leco Corporation, St. Joseph, MI).

### 2.6. Data analysis

Forage species and tillage system effects on soil indicators were evaluated using the appropriate strip-plot design with the PROC MIXED procedure of the Statistical Analysis System (SAS) (Littel et al., 1996). Replication and its interactions were considered random effects and treatments were considered fixed effects. Cone index determinations in 2002 were taken every 2 cm, but depth was averaged and analyzed for treatment comparisons from 0 to 10 cm, 10 to 20 cm, 20 to 30 cm, 30 to 40 cm, and 40–50 cm depth increments. Bulk density determinations were taken at five depths, but were averaged and analyzed for three depths (0–5 cm, 5–15 cm, and 15–25 cm). For cone index and bulk density analyses, row position and depth were analyzed as an expansion of the original design (strip-plot) to a strip-split-split-plot design (position as subplots and depth as sub-subplots). Soil organic carbon and total nitrogen data were analyzed using depth (sub-subplots) as an expansion of the original design (strip-plot) to a strip-split-plot design (Gomez and Gomez, 1984). Least-square means comparisons were made using Fisher's protected least significant differences (LSD). A significance level of $P \leq 0.05$ was established *a priori*.

## 3. Results and discussion

### 3.1. Cone index

Previous research on grazing annual ryegrass alone or in combination with other forage species in the Coastal Plain reported increased soil compaction in the soil surface (4–14 cm depth) compared to grazed rye (*Secale cereale* L.) (Miller et al., 1997). However in this study there was no difference between forage species for cone index in 2002 (data not shown). Tillage treatment effects on cone index (averaged over forage species and row positions) for three periods in 2002 are shown in Fig. 1. Summer tillage in 2001, prior to grazing in early winter 2002 (Fig. 1A) impacted cone index to 30 cm depth and indicated a 7-month residual effect of tillage. Paratilling decreased cone index to a depth of 30 cm, while chisel plowing exhibited lower cone index than no-till only in the upper 10 cm. A similar residual effect was reported by Touchton and Johnson (1982) when subsoiling prior to summer row crop significantly increased yield of a subsequent small grain grown without a second subsoiling between crops.

All three tilled treatments reconsolidated below 10 cm depth. At the 10–30 cm depth, both paratill treatments did not reconsolidate as much as chisel plowing. Mullins and Burmester (1997), reported that cattle compacted the soil to a depth of 15 cm on a silt–loam soil in north Alabama. In contrast, other studies have shown that compaction created by animal traffic during winter grazing is not restricted to the soil surface (Touchton et al., 1989; Miller et al., 1997). Touchton et al. (1989) reported that in a sandy loam soil in northern Alabama, soil compaction by animals can be as deep as 50 cm compared to ungrazed areas.

During mid-summer of 2002, when cotton and peanut were flowering and most sensitive to soil water deficits, paratilling and chisel plowing + disking imposed in April, just prior to planting, reduced compaction within the top 10 cm of soil (0–10 cm depth). Paratilling, whether with disking or with no surface tillage, significantly reduced soil strength to 40 cm. However, the chisel + disk tillage resulted in cone index similar to that of NT at 10–50 cm depths. These results confirm earlier observations that disking can reduce equipment-bearing capacity and thus exacerbate compaction in soils that readily form compacted layers called hardpans (Touchton et al., 1989; Reeves et al., 1992). No-tillage resulted in the highest values (close to 2.0 MPa near the soil surface), which would limit the ability of crop roots to expand into deep zones of moisture availability (Fig. 1C) (Reeves et al., 1992).

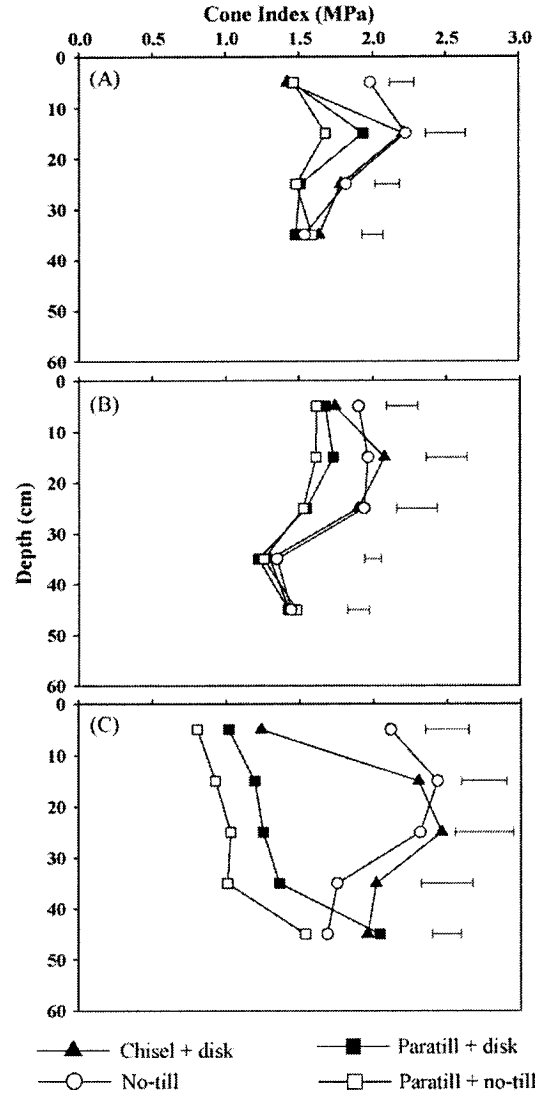


Fig. 1. Soil strength as affected by four tillage systems for cotton/peanut integrated with winter-annual grazing in three periods in 2002: (A) before grazing; (B) after grazing; (C) after summer tillage on a Dothan loamy sand in southeastern AL. Measurements were made to a depth of 40 cm (A) and to a depth of 50 cm for the other two sets of measurements (B and C) (data averaged over two forage species and three row positions). Horizontal bars are $LSD_{0.05}$.

Contour graphs showing cone index across five positions in July, 2003 are shown in Fig. 2. Paratill + no-till, paratill + disk or conventional tillage (chisel + disk) resulted in low and similar cone index values for each position (range: 0.4–1.2 MPa) to a depth of 15–20 cm (Fig. 2A, B, and D). In the chisel + disk tillage systems (Fig. 2D), cone index was greater below the depth of tillage (20–25 cm), reaching 2.0 MPa across the row and trafficked interrow. These results are consistent with those of Schwab et al. (2002), in which cone index was

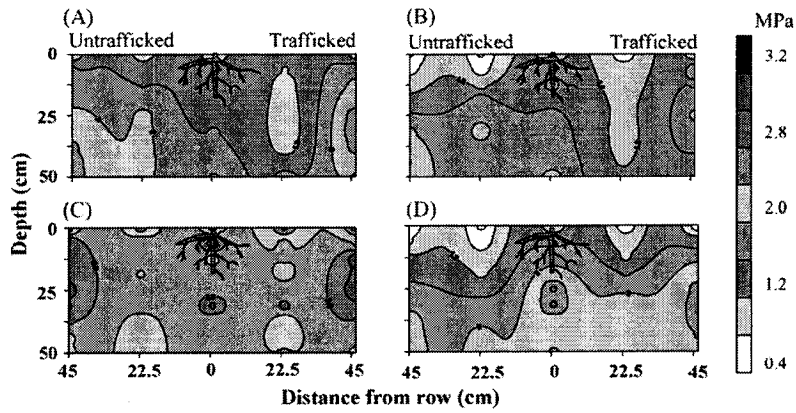


Fig. 2. Soil strength of four tillage systems for cotton/peanut integrated with winter-annual grazing: (A) paratill + no-till, (B) paratill + disk, (C) no-till, and (D) chisel + disk on 11 June, 2003 on a Dothan loamy sand in southeastern AL (averaged over forages). Untrafficked and trafficked interrow refers to traffic from tillage and planting operations as well as random passes for spraying agrochemicals. Root icon denotes position of cotton row.

greater below depths of 20–25 cm with chisel plowing. In no-till plots, cone index was high throughout the soil profile (95% of the values exceeded 2.0 MPa; Fig. 2C). The greater cone index in no-till could restrict root growth leading to decreased cotton and peanut yields (Burmester et al., 1993; Hartzog and Adams, 1989; Jordan et al., 2001). For deep tillage treatments (paratilling with or without disking), the zone of disruption of the paratill decreased cone index to a depth of 40–50 cm (<1.2 MPa; Fig. 2A and B). This deep and wide disruption was expected as the paratill was set to a depth below 40 cm and the paratill had bent shanks that lifted the soil, causing a very wide zone of disruption (≈60 cm) below the soil surface (Schwab et al., 2002).

### 3.2. Soil bulk density

With the exception of the 5–15 cm depth (1.70 versus 1.66 Mg m$^{-3}$, following ryegrass and oat species, respectively, $P = 0.09$), bulk density was not affected by forage species or forage species × position interaction (data not shown). Bulk density showed a significant tillage system × depth interaction during the third years of winter-annual grazing in the cotton–peanut–cotton cropping sequence. However, regardless of tillage system, bulk density was greater with increasing depth for all treatments (Table 1). Larger differences between no-till and other tillage systems were found at 0–5 cm depth in the untrafficked interrow

Table 1
Soil bulk density on 11 June, 2003, 40 days after cotton planting (averaged over forage species) as affected by tillage systems and row positions at three depths (0–5 cm, 5–15 cm and 15–30 cm) in an evaluation of two forages and four tillage systems for integrating winter-annual grazing in a cotton–peanut rotation on a Dothan loamy sand in southeastern AL (USA)

| Tillage systems | Sampling depth | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0–5 cm | | | 5–15 cm | | | 15–25 cm | | |
| | Untrafficked | In-row | Trafficked | Untrafficked | In-row | Trafficked | Untrafficked | In-row | Trafficked |
| Mg m$^{-3}$ | | | | | | | | | |
| Chisel + disk | 1.28 | 1.31 | 1.40 | 1.61 | 1.60 | 1.77 | 1.73 | 1.70 | 1.71 |
| Paratill + disk[a] | 1.24 | 1.39 | 1.40 | 1.62 | 1.64 | 1.70 | 1.70 | 1.67 | 1.72 |
| Paratill + no-till | 1.48 | 1.43 | 1.51 | 1.69 | 1.60 | 1.75 | 1.70 | 1.63 | 1.78 |
| No-till | 1.60 | 1.40 | 1.60 | 1.69 | 1.70 | 1.74 | 1.69 | 1.70 | 1.73 |
| LSD comparing two tillage means (columns) within a depth = 0.05 | | 0.05 | | | 0.03 | | | 0.03 | |
| LSD comparing two position means (rows) within a tillage = 0.05 | | 0.05 | | | 0.03 | | | 0.03 | |

[a] Non-inversion deep tillage using 'bent-leg' subsoiling.

position. Higher bulk density under no-till systems compared to conventional tillage systems has been reported before (Mielke et al., 1986). The trafficked interrow position had greater bulk density than after row positions (mainly at 5–15 cm depth) due to heavy equipment used for row crop production (Raper et al., 1998).

Paratilling (with or without disking) resulted in significantly lower bulk density compared to no-till in the untrafficked and trafficked interrow positions (0–5 cm depth) and under the row (5–15 cm and 15–25 cm depths). However, chisel + disk resulted in significantly lower bulk density compared to no-till for all positions at the 0–5 cm depth and in the untrafficked and in-row positions at the 5–15 cm depth. Below the 15 cm depth, no-till had lower bulk density than chisel + disk in the untrafficked position. Comparing paratill with and without disking, there was an interaction with depth and position. Without disking, bulk density was greater than with disking at 0–5 cm, but lower than with disking at 5–25 cm under the row.

### 3.3. Infiltration

Averaged across tillage systems, no differences were found between forage species for infiltration rates determined with the sprinkle infiltrometer. Averaged across forage species, no-till had the lowest infiltration rate (36%) of water applied. Paratill with or without disking and chisel plowing + disking had infiltration of around 80% (Fig. 3). Lower infiltration with no-till corresponded to higher bulk density and cone index under no-till (Figs. 1 and 2, and Table 1). Truman et al. (2002) reported that paratilling + no-till for cotton on a silt loam soil in northern Alabama had greater infiltration than no-till alone. Additionally, runoff was reduced by 215% after 8 months, compared to no-till.

For weakly structured Coastal Plain soils with high cone indices, paratilling (with or without disking) or chiseling + disking were sufficient to reduce cone index and bulk density, thereby improving water infiltration. These tillage systems also improved cotton and peanut yields compared to no-till for cotton and peanut, respectively (Siri-Prieto et al., 2003,2007)

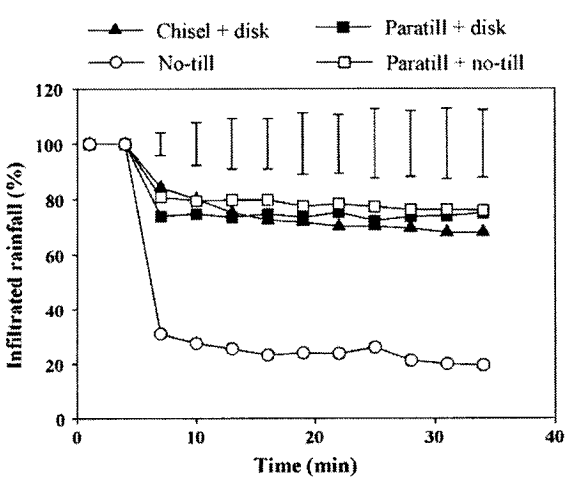


Fig. 3. Infiltrometer data for four tillage systems in a cotton/peanut rotation integrated with winter-annual grazing after 3 years (October 2003) on a Dothan loamy sand in southeastern AL (averaged over forage species). Vertical bars are $LSD_{0.05}$.

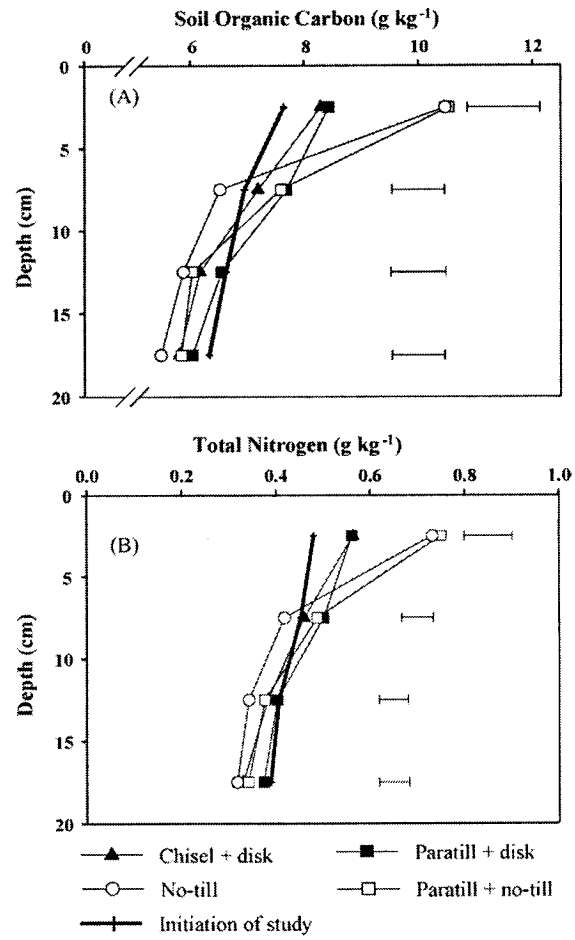


Fig. 4. Soil organic carbon (A) and total nitrogen (B) at the beginning of the experiment (original = October 2000) and after 3 years (September 2003) following four tillage systems in an evaluation of two forages for integrating winter-annual grazing in a cotton–peanut rotation on a Dothan loamy sand in southeastern AL (averaged over forage species). Horizontal bars are $LSD_{0.05}$ for comparing tillage system means; original SOC values for information only.

### 3.4. Soil organic carbon and total nitrogen content

There was a significant tillage × depth interaction for SOC and N concentrations. Soil organic C and N were greater in September 2003 than in October 2000 at a depth of 0–5 cm with no-till and paratill + no-till systems (Fig. 4A and B). Paratill with or without disking had greater SOC compared with no-till at 5–10 cm depth, but there were no significant differences in SOC among tillage systems elsewhere in the profile. Cultivated sandy Coastal Plain soils have very low SOC ($<10\ g\ kg^{-1}$), due to highly weathered soils and climatic conditions that cause rapid residue decomposition of SOC with tillage (Hunt et al., 1995; Motta et al., 2002). Intensifying soil C input by integrating a winter-annual forage crop into the cotton–peanut rotation, coupled with minimal surface soil disturbance (no-tillage or paratill + no-till) increased SOC in this soil after only 3 years. A similarly rapid increase in SOC on Coastal Plain soils was reported by Terra et al. (2005).

## 4. Conclusions

During 3 years of integrated winter-annual grazing in a cotton–peanut–cotton cropping sequence, the best tillage system for optimum infiltration, cone index, and bulk density was paratill without disking. This system increased SOC and total N at the soil surface (0–5 cm) by 38% and 56%, respectively at the end of 3 years. Paratilling without disking also resulted in the highest seed cotton and peanut yields (Siri-Prieto et al., 2007). Although paratilling is energy intensive, it requires the least draft of seven subsoiler designs commonly used in the southern USA, and can be done for less than $30/ha (Raper and Bergtold, 2007). For growers who integrate winter-grazing with cotton or peanut in the southern USA, annual paratilling with minimal soil surface disruption is recommended to sustain cotton and peanut yields while protecting soils from erosion, improving soil quality, and enhancing soil C.

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