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Integrating Winter Annual Grazing in a Cotton-Peanut Rotation: Forage and Tillage System Selection

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Abstract

Integrating livestock into cotton (*Gossypium hirsutum* L.)- peanut (*Arachis hypogaea* L.) rotations offers alternatives for grazing and crop management, but could result in excessive soil compaction, which can severely limit yields. We began a study in fall 2000 at the Alabama Agricultural Experiment Station's Wiregrass Research and Extension Center in southeastern Alabama on a Dothan sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) to develop a conservation tillage system for integrating cotton and peanut production with winter annual grazing of stocker cattle under dryland conditions. Results from the 2000-2001 and 2001-2002 seasons are presented in this paper. Winter forages and summer tillage were evaluated in a strip plot design with four replications. Winter pastures were oat (*Avena sativa* L.) and ryegrass (*Lolium mutiflorum* L.) for grazing and tillage systems were: 1) Moldboard plow +disking, 2) in-row subsoiling with a KMC subsoiler (14-16 in. depth) +disking, 3) No-till with KMC subsoiling 4) Paratill (18-20 in. depth) +disking, 5) No-till with Paratilling 6) strict No-till, 7) Disking, 8) Chisel plow + Disking. We evaluated biomass forage production, animal gain, soil strength, soil cover, plant population, and cotton lint and peanut yield. There were only minor differences in forage produced and animal gain. Soil compaction was increased by grazing to the 4-6 in. depth but conventional tillage or conservation tillage with non-inversion deep tillage alleviated this problem. Strict no-till following ryegrass had the highest soil cover (74%). Cotton and peanut plant populations were better following oat than ryegrass (cotton: 34,800 and 27,800 plants acre^{-1} for oat and ryegrass, respectively; peanut: 34,200 and 31,100 plants acre^{-1} for oat and ryegrass, respectively). Strict no-till had the lowest plant stand for both crops, but deep tillage (in row subsoiling or paratill) eliminated this problem. Cotton and peanut yields were affected by pasture and tillage systems interactions; however, peanut yield following oat was greater in all tillage systems except for the moldboard treatment. Strict no-till resulted in the lowest yields (<17% and <42% than the overall mean for lint cotton yield and peanut yield, respectively), and deep tillage was necessary to maximize yields in no-till. Oat appears less risky than ryegrass due to better

cotton and peanut yield in summer and similar animal gain in wintertime. In this region, integrating grazing in a row-crop system can be achieved using non-inversion deep tillage in a conservation system, offering producers the ability to increase income during winter without decreasing summer cash crops yield.

Keywords: Conservation Tillage, Soil Compaction, *Lolium mutiflorum* L., *Avena sativa* L., Paratilling, In-row Subsoiling, Integrated Systems.

Introduction

Recent research in Alabama found that contract grazing of stocker cattle in winter-early spring (100 to 140 days) offers returns from $70 to $225 per acre (Bransby et al., 1999). Such a system is ideal for small farmers with limited capital and offers potential for added income for producer's doublecropping behind winter grazing of annual pastures.

Soil management strategies that improve soil quality include conservation tillage, cropping intensification, and inclusion of sod-based rotations. Crop rotation is critical to cropping intensification and has long been recognized as being agronomically and economically beneficial (Bayer et al.2000; Reeves, 1994). Short-term forage rotations with row crops not only offer reduced economic risks for producers but also could increase soil organic carbon, improving soil quality and productivity and enhancing profitability for producers. However, winter-annual grazing results in excessive soil compaction, which can severely limit yields of double-cropped cash crops (Miller et al., 1997). Additionally, little is known about the direct impact of short-term grazing on soil properties. The degree of soil compaction varies with soil texture, soil water, grazing intensity, and vegetation type and climate regime (Taboada and Lavado, 1988). Two soil processes can occur in response to animal traffic. Compression by hooves predominates at low to medium soil moisture and plastic flow predominates in wet soil (Sholefield et al., 1985).

One method of alleviating compaction and recovering soil productivity is to subsoil to a depth of 12-20 inches (Raper et al., 1994). In-row subsoiling at planting is frequently used to alleviate soil compaction for cotton grown on sandy coastal plain soils. Research in Alabama indicates that peanut producers experienced problems with poor seedbed conditions in no-till systems due to compaction (Hartzog and Adams, 1989). Deep tillage has not resulted in sufficient yield increases to justify this practice in conventional tillage, but in no-till systems this practice has shown good responses (Oyer and Touchton, 1988). Tillage requirements for cotton and peanut following winter-annual grazing have not been researched or developed.

The objective of this study was to compare two winter pasture forages under grazing and their residual effect on cotton and peanut production, determine depth and degree of compaction from grazing, and determine an optimal tillage system for plant stand establishment and yield for cotton and peanut grown following winter annual grazing.

Materials And Methods

An experiment was established in November 2000 on a well-drained Dothan sandy loam at the Wiregrass Research and Extension Center (31^{o} 24'N, 85^{o} 15'W) in the Coastal Plain of southeastern Alabama. The climate is humid, with a mean annual air temperature of 64^{o} F and an average annual precipitation of 60 inches. Winter forages and summer tillage were evaluated in a strip-plot design with four replications. Winter forages (main plots) were oat and ryegrass. Oat (140 lb acre^{-1}; 'Harrison' in 2000 and 'Mitchell' in 2001) was seeded on 20 Oct. 2000 following disking/leveling and on 10 Nov. 2001 using a no-till drill. Ryegrass ('Marshall') was seeded (30 lb acre^{-1}) the same dates as oat by broadcasting following disking/leveling. Grazing was continuous as contract grazing from January 31 to April 11 (70 days grazing) and from January 22 to April 15 (84 days grazing) for 2001 and 2002, respectively. The stocking rate was two animals acre^{-1}.

Dry matter samples of winter forage were collected from each replication using small cages (9.0 ft^2) on January 31 (day 0), March 8 (day 37), and April 11 (day 70) in 2001 and on January 22 (day 0), February 21 (day 30), March 21 (day 58), and April 15 (day 84) in 2002, starting when the cattle entered the experiment. After each forage harvest, the cage was moved to another location within the plot that was grazed. A subsample (4.0 ft^2) was taken from each cage, dried in a forced-air oven at 60^o C for 48 h, and weighed to determine dry matter. Beef cattle performance was measured by weighing on January 31 (day 0), February 28 (day 28), March 24 (day 52), and April 11 (day 70) in 2001 and January 22 (day 0), February 21 (day 30), March 21 (day 58), and April 15 (day 84) in 2002.

During the spring-summer, the experimental area was divided into peanut and cotton areas which were rotated each year. The summer crop tillage practices were: 1) moldboard plowing (12-in. depth)+ disk/level (4-6 in. depth) after winter forage; 2) in-row subsoiling with a KMC (Kelley Manufacturing Co. Tifton, GA[1]) (14-16 in. depth) + disk/level; 3) No-till with KMC in-row subsoiling. 4) under-the-row paratilling (18-20 in. depth) + disk/level; 5) No-till with paratilling; 6) strict no-till; 7) disk/level only; 8) chisel plowing (8-in depth) + disk/level. Tillage plots were 50-ft long and 24-ft wide with 8, 36-in. rows. 'Suregrow 125 B/R' cotton was seeded at 45,000 seed acre^{-1} on 25 May 2001 and 'SG 501 BRR' at 47,000 seed acre^{-1} on 24 May 2002. 'GA Green' peanut was seeded at 103 lb acre^{-1} on 25 May 2001 and 24 May 2002. Cultural practices for winter annual grazing and summer crops were recommended by the Auburn University Extension Service. Lime, P and K were applied according to Auburn University soil test recommendations.

Plant residue cover was determined by a line-transect method immediately after summer crop planting. A measuring tape was stretched diagonally across each plot. Whether plant residue greater than 0.1 in. wide was touching the tape or not was determined every 2-in. Residue cover was calculated by dividing the number of points having residue touching the tape by the total number of points evaluated.

Three tillage treatments were selected for evaluation in order to determine soil strength (No-till + paratill, chisel +disk and strict no-till). Soil strength was determined using a RIMIK CP 20 Cone Penetrometer (Rimik Agricultural Electronics, 1994[1]). Cone index measurements (ASAE, 1999) were taken in 2002 on three dates (January 20, April 12 and July 28). Readings were taken when the soil water content was near field capacity. Recordings were made in three positions: 1) in the row; 2) in the untrafficked row middle (18-in. from the row); and 3) in the trafficked row middle (18-in. from the row). Five insertions were made at each position in both crops from the middle of the plot (row fourth). A penetrometer cone with a base area of 0.05 in. was used to a depth of 16-in. **on** January 20 and to a depth of 20 in. for the other two sets of measurements (April 12 and July 28) (1-in. increments for all measurements). Average volumetric water content was determined when soil strength measurements were taken in the top 8 in. of soil. This determination was performed in-row, in the nontrafficked middle, and in the trafficked middle at one location in each plot. A Tektronix 1502C (Tektronix, Inc. Beaverton, OR[1]) cable tester was used for soil water determination using time-domain reflectometry (Topp, 1980). Average soil water contents were 18%, 18.5%, and 17.5 % for January 20, April 12, and July 28, respectively.

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[1] Use of company name does not imply USDA approval or recommendation of the product or company to the exclusion of others which may be suitable.

Plant populations for peanut and cotton (approximately two weeks after sowing) were determined in 2001 and 2002 by counting the number of plants along 32.8-in. lengths of randomly selected rows (3 sections per plot in all treatments). Cotton lint yields were determined from 50 ft. of two rows selected from the middle four rows of each plot and ginning percentage was measured in the lab from subsamples ginned with a laboratory cotton gin with 20-saws 5-in. in diameter and a brush with 7-3/8 in. in diameter (Dennis MFG. Co. Inc. Athens, Texas[1]). Peanut yields were determined in a similar fashion with grades determined from subsamples.

All data were subjected to analysis of variance (ANOVA) using the Statistical Analysis System (SAS Institute, 1998). Variances for forage species were not equal among harvest dates; so separate ANOVAs were done for each harvest date. Where forage species X tillage system interactions occurred for response variables, data were analyzed and are presented by forage species. For cone index, the data were averaged over all three positions (for each time). Except for forage harvest date and animal daily gain, the data were combined over both years for analysis, as there were no year X treatment interactions on the other response variables. Sources of variation were considered significant when the probability of greater F values were ≤ 0.05. Means separations were made with LSD ($P \leq 0.05$) when sources of variation from the ANOVA were significant.

Results And Discussion

Forage Biomass and Animal Gain

In both years (2001 and 2002, but only significant in 2001), oat produced more dry matter than ryegrass at grazing initiation, but by the end of grazing these differences disappeared since oats have a shorter growth cycle and ryegrass starts producing more dry matter in late spring (Table 1)(SCS-1998-36). This is one reason that in a wide range of grazing experiments evaluating different winter annual pastures for stocker production, ryegrass was considered better than small grains (Bransby et al., 1999). In our study, we found no practical differences between forage species for biomass production, suggesting that both forages responded to grazing pressure in a similar fashion.

Average daily gain (ADG) for both years was 3.05 and 3.25 lb acre^{-1} for oat and ryegrass, respectively, indicating an excellent response to grazing (Table 2). In 2002, oat performed better in the beginning, but ryegrass produced more biomass at the end of the grazing period, which resulted in better animal gain later in the season. Bransby et al. (1999) reported similar results working with ryegrass and they concluded that it is possible to achieve weight gains on ryegrass pastures that are similar to those observed in feedlots.

Gross return averaged $153 per acre (Table 3). A pasture variable cost of $75 per acre (assuming cost of growing the pasture, medication, implants, and labor) indicates a potential for farmers to make money in wintertime. The cost of inputs, levels of production per animal and per acre, as well as the length of the grazing season, impact the cost per pound of gain. Also, pasture management that results in vigorous, productive forage stands, as well as proper grazing management decisions are integral for success.

Penetrometer Measurements

Soil strength for tillage systems at three periods in 2002 are shown in Fig. 1. The data were averaged over all three positions. Tillage system significantly affected soil strength in all periods measurements were taken. In the first graph (A, January 20, 2002), measurements were taken before grazing. In the first 12 in. there were differences between tillage systems. This indicates a residual effect of tillage from spring 2001 evident after 7 months. Paratilling presented the lowest soil strength to a depth of 12 in., and chisel exhibited lower soil strength than no-till only in the upper 4 in. A similar residual effect has also been reported by Touchton and Johnson (1982) in which subsoiling a summer row crop provided significant yield benefits to the subsequent small grain double crop without the need for a second subsoiling operation between crops.

After grazing (B, April 14, 2002), differences among tillage systems were smaller than before grazing (A, January 20, 2002). Cattle had compacted the surface soil to a depth of approximately 4-6 in. These results agree with those of Mullins and Burmester (1997), who found that cattle compacted the soil surface to a depth of 6 in. on a silt-loam soil in North Alabama. In the third graph (C, July 28, 2002), paratilling or chiseling eliminated this compaction caused by grazing and strict no-till presented the highest values (close to 20 bars), potentially limiting root growth. Busscher et al. (1988) found that soils that were disked had on average lower soil strength than conservation-tilled soils throughout the upper 24 in. of the profile. They attributed the lower soil strength in conventional tillage to loosening of the surface layer by disking.

Residue Cover

The forage species X tillage systems interactions were significant for residue cover. All no-till systems with ryegrass had the best cover residue. On the other hand, conventional tillage presented no difference in residue cover regardless of forage species. Strict no-tillage had the highest residue cover following both forages species. All no-till systems had the highest percent ground cover: 52, 54 and 65% for no-till + KMC, No-till + paratill, and strict no-till, respectively following oat, and 56, 62 and 74% for no-till + KMC, no-till + paratill, and strict no-till, respectively, following ryegrass (Table 4). Based on the definition that any tillage system that leaves at least 30% of the soil surface covered with crop residues can be regarded as conservation tillage (CTIC, 1994), all three no-till systems in this experiment qualified as conservation tillage. Thus, grazing annual forages can provide sufficient residue to qualify as a conservation practice in farm programs. However, increased residue quantity and not surface soil coverage *per se* is critical to increasing soil carbon and improving soil quality.

Cotton Population and Yield

Cotton plant density was lower in 2001 (30,400 plants acre^{-1}) than in 2002 (32,200 plants acre^{-1}), but no interaction between forages and years occurred for this variable. There was an interaction among tillage systems and years (data not shown). Strict no-till had the lowest plant population in both years, but the magnitude of this difference among tillage systems varied between years. Plant population was affected by forage species (34,800 and 27,800 plants acre^{-1} for oat and ryegrass, respectively, averaged across years) (Table 5). The best plant stands were under oat forage in all tillage systems, indicating no interaction between forage species and tillage system. Plant stands associated with forage residues was partially due to mechanical problems, which prevented good seed to soil contact. No penetrometer readings were taken at planting in both years due to dry soil conditions, but there was visible evidence that seedbed problems occurred with ryegrass residue. Averaged over forage species, strict no-tillage had the lowest plant stand (23,900 plants acre^{-1}), but deep tillage alleviated this problem. Comparing the two deep tillage systems in no-till (under-the-row KMC or paratilling), there was no difference between these two non-inversion forms of deep tillage, but there was a consistent trend toward increased plant stands with KMC in-row subsoiling compared to paratilling following ryegrass. Tillage system choice was more critical following ryegrass than oat in relation to plant stands.

Lint cotton yield averaged 1200 lb acre^{-1} in 2001 and 985 lb acre^{-1}in 2002. Even though there was a difference between years, no forage species X year or tillage system X year interactions occurred for lint yield. There was no significant difference between forage species;

plant populations affected by forage had no impact on yield for these two years. Cotton lint yields were affected by forage species and tillage system interactions, however, strict no-tillage (930 lb lint cotton/acre averaged over forages) resulted in the lowest lint yields (18% less than the mean) for both species and deep tillage was necessary to maximize yields. Reeves and Mullins (1995) reported similar results, indicating that subsoiling was necessary for maximum cotton yields in coastal plain soils with root-restricting soil layers. Cotton required more intensive tillage or more aggressive non-inversion deep disturbance (paratilling) to maximize lint yield following grazing of ryegrass compared to grazing of oat (1120 and 950 lb acre^{-1} in ryegrass and 1110 and 1110 acre^{-1} in oat for no intensive tillage and intensive tillage, respectively). Comparing average lint yields for full-season non-irrigated cotton variety trials at the location (1030 lb acre^{1}) in 2001 with the average for this experiment (1200 lb acre^{1}) in the same year, doublecropping cotton following winter-annual grazing allows for extra income without sacrificing cotton yields.

Peanut Population and Yield

Peanut plant density was lower in 2002 (30,100 plants acre^{-1}) than in 2001 (35,100 plants acre^{-1}), but no interaction between forages and years occurred for peanut density. There was a difference among tillage systems and years (data not shown). Strict no-tillage had the lowest plant population in 2001, but had similar plant population with respect to overall means in 2002. Plant population was affected by previous forage species (34,200 and 31,100 plants acre^{-1} for oat and ryegrass, respectively) (Table 6). The best plant stands were following oat forage (averaged over all tillage systems), but a forage species X tillage system interaction existed. Strict no-tillage under ryegrass had the lowest plant stand (17,300 plants acre^{-1}), but deep tillage alleviated this problem. No significant differences in plant density existed in no-till treatments between deep tillage under ryegrass, but under oat, in-row KMC subsoiling resulted in increased plant stands compared to paratilling.

Peanut yields averaged 3800 lb acre^{-1} in 2001 and 3250 lb acre^{-1}in 2002. Even though there was a difference between years, no forage species X year interaction occurred for yield. Tillage system X year interactions occurred for peanut yield due to strict no-till, which had the lowest yield in 2001 while strict no-till and moldboard had the lowest yields in 2002 (data not shown). There was a significant difference between forage species (Table 6). The reason for peanut following oat having a higher yield than peanut following ryegrass did not appear to be related to plant density. Table 6 shows that for all conventional tillage treatments (chisel, moldboard, and disk/with or without deep tillage), peanut plant populations were similar for both forages, but in conservation systems (no-till strictly or with deep tillage), plant populations were better following oat than ryegrass. Peanut yields were affected by forage species and tillage system interactions. Moldboard was the only tillage system where peanut yield was equal between the two forages species (3500 lb acre^{-1} and 3550 lb acre^{-1} for oat and ryegrass, respectively). The other seven tillage systems showed higher peanut yields following oat. In our study, no relationship could be established between soil strength and forage species measured 2 months after planting in 2002, but it was obvious that some factor was limiting peanut growth and yield following ryegrass. One reason could be that ryegrass produced more root biomass that limited the following crop. Strict no-tillage (2162 lb acre^{-1} averaged over forages) resulted in the lowest yields (42% less than the mean) and deep tillage was necessary to maximize yields. In-row subsoiling yields were higher than for paratilling within no-tillage, but were similar under conventional tillage systems. Deep tillage in no-till systems was more important following ryegrass than oat forage. These results agree with those of Oyer and Touchton (1988), who found advantages to previous deep tillage in a no-till system (24% increase in peanut yield averaged over two years), but no advantages of in-row subsoiling in conventional tillage systems.

Conclusions

Our study shows that integration of winter-annual grazing in cotton production can enhance profitability for Southeastern producers. Soil compaction was affected by grazing in the first 4-6 in., and summer tillage (conventional or non-inversion deep tillage) alleviated this problem. Ryegrass in strict no-till resulted in the best soil cover (up to 74%), but reduced plant stands in both crops. Cotton and peanut yields were affected by pasture and tillage system interactions; however, peanut yield following oat was significantly better in all tillage systems except moldboard plowing. Oat appears to be a better choice than ryegrass for peanut and cotton grown following winter grazing. Strict no-till resulted in the lowest yields (17% and 42% less than the overall mean for lint cotton yield and peanut yield, respectively), and deep tillage was necessary to maximize yields. Within no-tillage systems, peanut yields were greater with in-row subsoiling using the narrow-shanked KMC implement compared to paratilling. Cotton lint yields, however, were similar with the two non-inversion deep tillage methods used in conjunction with no-tillage. In conclusion, integrating winter annual grazing with cotton or peanut can be achieved using non-inversion deep tillage in conservation tillage systems. Oat appears less risky than ryegrass due to better cotton and peanut yield in summer and similar animal gain in wintertime. Integrating winter annual grazing offers producers the ability to increase income during winter months without sacrificing peanut or cotton yields.

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Table 1. Forage production for oat and ryegrass at different harvest dates during 2001 and 2002, Wiregrass Station, AL.

	2001			2002			
	Biomass grazing time			Biomass grazing time			
	---------------- days --------------			---------------------- days ----------------------			
	0 †	37	70	0 †	30	58	84
Forage species	--------------ton acre^{-1}-----------			---------------------ton acre^{-1}-------------------			
Oat	0.89	0.49	0.79	0.45	0.73	1.05	0.77
Ryegrass	0.4	0.43	0.76	0.28	0.51	0.92	0.85
$LSD_{0.05}$	0.31	ns‡	ns	ns	ns	ns	ns

†biomass produced before starting grazing

‡not significant

Table 2. Animal Daily Gain (ADG) as affected by forage species for different grazing periods in 2001 and 2002, Wiregrass Station, AL.

	2001			2002		
	Animal Daily Gain grazing time			Animal Daily Gain grazing time		
	--------------- days ---------------			--------------- days ---------------		
	0-28	28-52	52-70	0-30	30-58	58-84
Forage species	----------lb cow^{-1} day^{-1}----------			---------- lb cow^{-1} day^{-1}----------		
Oat	3.65	3.15	1.99	3.53	2.83	3.00
Ryegrass	3.84	2.91	2.95	3.48	2.88	3.14
$LSD_{0.05}$	ns†	ns	0.52	ns	ns	ns

†not significant

Table 3. Gross return ($/acre) and days grazing as affected by forage species in 2001 and 2002, Wiregrass Station, AL.

Year	Forage species	Gross Return ($/acre)†	Days grazing
2001	Ryegrass	154	70
	Oat	141	
2002	Ryegrass	160	84
	Oat	158	

†based on price under contract and two head/acre stocking rate^{-1}. 2001 = $0.335/lb and 2002 = $0.30/lb

Table 4. Percent surface residue cover in cotton and peanut plots (average) immediately after seeding as affected by tillage systems and forage species, Wiregrass Station, AL. Data are averaged over 2 yr (2001 and 2002).

	Surface residue cover	
	Forage species	
Tillage systems	Oat	Ryegrass
	--------------% -------------	
Moldboard + disk	2.2	2.0
Disk	15.3	15.7
Chisel + disk	14.5	16.3
No-till + KMC	52.2	55.5
No-till + paratill	53.9	61.8
No-till	64.8	74.0
Mean	*34.0*	*38.0*
$LSD_{0.05}$ (forage)	2.9	
$LSD_{0.05}$ (tillage system X forage)	5.1	

Table 5. Effect of winter forages species and tillage systems on cotton plant populations and lint yield at Wiregrass Station, AL. Data are averaged over 2 yr (2001 and 2002).

	Plant density			Lint yield	
	Forage species			Forage species	
Tillage systems	Oat	Ryegrass	*Mean*	Oat	Ryegrass
	---------plants acre^{-1} -----------			------lb acre^{-1} ------	
Moldboard + disk	35,800	32,700	*34,300*	1,005	1,059
Disk	35,100	29,100	*32,100*	1,111	1,117
Chisel + disk	34,000	28,900	*31,400*	1,110	1,142
KMC + disk	35,900	29,800	*32,900*	1,171	1,120
No-till + KMC	34,300	28,700	*31,500*	1,174	1,079
Paratill + disk	37,500	30,700	*34,100*	1,117	1,162
No-till + paratill	35,400	24,900	*30,200*	1,141	1,119
No-till	30,200	17,700	*23,900*	1,049	818
Mean	*34,800*	*2,7800*	*3,1300*	*1,110*	*1,077*
$LSD_{0.05}$ (forage)	2,000			*ns*†	
$LSD_{0.05}$ (tillage system)	5,300			77	
$LSD_{0.05}$ (tillage system X forage)	*ns*			100	

†*not significant*

Table 6. Effect of winter forages species and tillage systems on peanut plant populations and yield at Wiregrass Station, AL. Data are averaged over 2 yr (2001 and 2002).

	Plant density		Yield	
	Forage specie		Forage specie	
Tillage systems	Oat	Ryegrass	Oat	Ryegrass
	-----plants acre^{-1}------		-------lb acre^{-1}-------	
Moldboard + disk	36,100	35,000	3,515	3,553
Disk	33,900	33,000	4,088	3,384
Chisel + disk	34,100	33,800	4,012	3,416
KMC + disk	34,400	33,300	3,983	3,436
No-till + KMC	39,000	32,600	4,292	3,545
Paratill + disk	33,300	32,600	4,114	3,359
No-till + paratill	34,100	31,000	4,112	3,217
No-till	28,500	17,300	2,914	1,410
Mean	*34,200*	*31,100*	*3,879*	*3,165*
$LSD_{0.05}$ (forage)	2,100		169	
$LSD_{0.05}$ (tillage system)	3,700		257	
$LSD_{0.05}$ (tillage system X forage)	3,200		408	

Fig. 1. Soil strength as affected by three tillage systems for three periods in 2002: A (before grazing, Jan. 30); B (after grazing, Apr. 14); C (after summer tillage, Jul. 28) at Wiregrass Station, AL, 2002. Data averaged over forage species (oat and ryegrass) and row position (row, untrafficked row, and trafficked row). Measurements made to a depth of 16-in. Jan. 20 and to a depth of 20 in. for the other two sets of measurements (Apr. 12 and Jul. 28). Horizontal bars are $LSD_{0.05}$.