Tillage Requirements for Integrating Winter-Annual Grazing in Peanut Production: Plant Water Status and Productivity

G. Siri-Prieto,* D. W. Reeves, and R. L. Raper

ABSTRACT

The use of crop rotation systems involving winter-annual grazing can help peanut (*Arachis hypogaea* L.) producers increase profitability, although winter-annual grazing could result in excessive soil compaction, which can severely limit yields. We conducted a 3-yr field study on a Dothan loamy sand in southeastern Alabama to develop a conservation tillage system for integrating peanut with winter-annual grazing of stocker cattle under dryland conditions. Winter-annual forages and tillage systems were evaluated in a strip-plot design, where winter forages were oat (*Avena sativa* L.) and annual ryegrass (*Lolium mutiflorum* L.). Tillage systems included moldboard and chisel plowing, and combinations of noninversion deep tillage (none, in-row subsoil, or paratill) with/without disking. We evaluated soil water content, peanut leaf stomatal conductance, plant density, peanut yield, peanut net return, and total system annual net return. Peanut following oat increased soil water extraction (15%), stands (12%), and yields (21%) compared with peanut following ryegrass. Strict no-till resulted in the lowest yields (2.29 Mg ha^{-1}, 42% less than the mean) and noninversion deep tillage (especially in-row subsoil) was required to maximize water use and yields with conservation tillage. Net return from annual grazing ($185 ha^{-1}, USD) represented 40% of the total return for the best treatment (no-tillage with in-row subsoil following oat = $462 ha^{-1}). Integrating winter-annual grazing in this region using noninversion deep tillage following oat in a conservation tillage system can benefit peanut growers, allowing extra income without sacrificing peanut yields.

The southeastern United States contains 11% of the nation's farms. Two-thirds of these farms have livestock operations, with beef being the most common. Recent research in Alabama found that contract grazing of stocker cattle supplied by independent cattle owners in winter and early spring offers farmers net returns from $170 to $560 ha^{-1} for grazing periods of 100 to 140 d (Bransby et al., 1999). Such a system is ideal for farmers with limited capital and also allows potential for added income for producer's double-cropping behind winter grazing of annual pastures.

Of the 577,000 ha^{-1} of peanut grown in the United States, only 75,000 ha^{-1} (13.9%) were planted in conservation tillage in 2002 (Conservation Technology Information Center, 2004). After decades of conventional tillage practices, millions of hectares of croplands in the region are degraded or producing below their economic potential, causing more difficult management decisions (Reeves, 1994).

Peanut production has traditionally been a tillage intensive operation, and peanut yields have not increased for a number of years, even with new varieties and technology. In addition, perennial forage or sod-based rotations, which are a highly effective weapon against some peanut diseases, are not widely used due to the absence of profitable rotation crops (Bowen et al., 1996; Hagan et al., 2003). Since 2002, changes in Farm Bill peanut marketing programs have forced producers to reduce costs and increase peanut productivity to remain competitive.

Sod-based systems and crop rotation have shown success in improving yield and reducing the risk of disease damage (Hagan et al., 2003). Sod-based rotation can also improve soil quality, such as soil organic carbon, water infiltration, rooting depth, and aggregate stability (Varvel, 1994; Reeves, 1997; Hagan et al., 2003). However, short-term (winter-annual) grazing rotations can result in excessive soil compaction, which can severely limit yields of double-cropped cash crops (Miller et al., 1997). Research in Alabama indicates that peanut producers have experienced problems with poor seedbed conditions in no-till systems due to soil compaction (Colvin et al., 1988; Hartzog and Adams, 1989; Jordan et al., 2001). In general, peanut response to conservation tillage has been variable in the last 20 yr due to issues such as weed control, diseases, hardpan, pod digging, and weather conditions (Hartzog and Adams, 1989; Grichar, 1998; Johnson et al., 2001; Jordan et al., 2001). These factors have limited the adoption of conservation tillage by peanut farmers. Traffic, plow, or natural hard pans in coastal plain soils have made in-row subsoiling a popular tillage method to alleviate soil compaction (Colvin et al., 1988). Inclusion of noninversion deep tillage (in-row subsoil) in a no-till system has shown acceptable responses in peanut production,

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Abbreviations: AAES, Alabama Agricultural Experiment Station; ACES, Alabama Cooperative Extension System; DOY, day of year; DWG, daily weight gain; SMK, sound mature kernels.

although, responses to in-row subsoil in conventional tillage systems does not justify this practice (Oyer and Touchton, 1988). No research has been conducted in identifying tillage requirements for peanut following winter-annual grazing.

The objectives of this study were to determine the feasibility of double-cropping peanut following winter-annual grazing of stocker cattle in the southeastern Coastal Plain and to identify an optimal choice of forage and tillage system combination for net return, peanut productivity based on yield, plant stand, soil water content, and leaf stomatal conductance responses. The results presented here emphasize peanut productivity and system profitability.

MATERIALS AND METHODS

Site Description

Our experiment began October 2000 and was conducted for 3 yr at the Alabama Agricultural Experiment Station's (AAES) Wiregrass Research and Extension Center (31°24′ N, 85°15′ W) in the Coastal Plain of southeastern Alabama. The soil was a well-drained Dothan loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults). The site had been cropped previously in a cotton (*Gossypium hirsutum* L.)-peanut rotation since 1994, and managed according to recommendations of the Alabama Cooperative Extension System (ACES). The climate for this area is humid subtropical, with a mean annual air temperature of 18°C and 1400 mm annual precipitation.

Winter forages and summer tillage practices were evaluated in a strip-plot design with four replications. Two winter-annual forages (oat and annual ryegrass) served as horizontal treatments and eight tillage systems served as vertical treatments.

Cultural Practices

Forage plots were 100 m long by 61 m wide. At the beginning of the experiment (October 2000), all plots were disked and seeded with oat and ryegrass with a no-till drill (Great Plains Mfg. Inc., Salina, KA).[1] Phosphorus, K, and lime applications for forages and peanut were based on ACES soil test recommendations (Adams and Mitchell, 2000). The winter-annual forages were fertilized with an average of 140–40–40–20 kg ha^{-1} of N–P–K–S; P and K applications varied somewhat each year based on soil test results and resultant Alabama ACES recommendations. All winter-annual forages were terminated before summer tillage with an application of 0.9 kg a.i. ha^{-1} glyphosate approximately 4 to 6 wk before peanut planting. Yearling Angus × Simmental steers (*Bos taurus* L.; $n = 24$) weighing 260 ± 20 kg (initial body weight) were used in the study, supplied by independent cattle owners, and stocked on a contract-grazing basis at a rate of five head ha^{-1} for winter > 70 d. All steer received commercial growth-promoting implants. Total daily weight gain (DWG) per hectare was determined by multiplying DWG by the stocking rate used in the experiment.

The entire grazed experimental area was divided in half for planting peanut and cotton and imposing tillage treatments. One half of the area was planted to peanut, and the other half was planted to cotton. The peanut and cotton areas were rotated each year (2000–2003), allowing cropping of both phases of the peanut-cotton rotation each year. The experimental design and tillage treatment plot arrangement was identical for both areas each year, and each experimental tillage treatment unit (plot) in both cropping areas received the same tillage treatment each year of the study. Tillage plots within these areas were 15.2 m long and 7.3 m wide, with eight 0.92-m rows. The eight summer tillage practices were (i) moldboard plowing to a depth of 30 cm and disking or leveling (10- to 15-cm depth); (ii) disking or leveling only; (iii) chisel plowing to a depth of 20 cm and disking or leveling; (iv) in-row subsoiling with a narrow-shanked subsoiler (KMC, Kelley Manufacturing Company, Tifton, GA) to a depth of 35 to 40 cm and disking or leveling; (v) no-till with in-row subsoiling; (vi) under-the-row Paratilling with a bent-leg subsoiler (Paratill, Bigham Brothers, Lubbock, TX) to a depth of 45- to 50-cm and disking or leveling; (vii) no-till with Paratilling; and (viii) no-till. Treatments i through iv and vi are forms of conventional tillage and result in a smooth, bare soil surface. Treatments v, vii, and viii are all variations of conservation tillage. The KMC narrow-shanked subsoiler is equipped with a coulter to cut residue ahead of the shank, and with pneumatic closing wheels following the shank. When used alone, it disrupts a narrow strip 10- to 16-cm wide at the soil surface, directly in the seeding zone, with very little residue disturbance. The Paratill bent-leg subsoiler shanks also are equipped with a coulter to cut residue, but the shanks operate offset at a 45° angle to lift the soil beneath the row. The vertical portion of the shank operates offset from the row area, resulting in a narrow (10- to 16-cm) zone of surface soil disruption about 30-cm from the row. The Paratill was equipped with a smooth metal drum-type roller to level the soil surface. All tillage operations were performed after the removal of cattle from the winter-annual forages. Planting dates, densities, and varieties for forages and peanut, as well as grazing times, are listed in Table 1. Tillage and planting equipment were guided using a tractor equipped with a Trimble AgGPS Autopilot automatic steering system (Trimble, Sunnyvale, CA), capable of centimeter-level precision, which reduced equipment-induced compaction near the peanut row. A four-row John Deere MaxEmerge planter (Deere & Co., Moline, IL) was used to plant peanut. This planter was designed for no-till planting with heavy-duty down pressure springs, and a floating residue manager. No lime or fertilizer was used for peanut in any year. Alabama Cooperative Extension System recommendations were used to apply all herbicides, insecticides, and fungicides. Early leaf spot (*Cercospora arachidicola* Hori), late leaf spot (*Cercosporidium personatum* Berk & Curtis), and southern stem rot (*Sclerotium rolfsii* Sacc.) were controlled with applications of chlorothalonil and tebuconazole. The center two rows were inverted at maturity (9 Oct. 2001, 4 Oct. 2002, and 5 Sept. 2003) and harvested (12 Oct. 2001, 8 Oct. 2002, and 9 Sept. 2003) for determination of peanut yields.

Data Collection

Peanut plant populations (2 wk after sowing) were determined in all years. Plants were counted along 10-m lengths of randomly selected rows (three sections per plot in all treatments). After harvest, peanuts were dried to a 100 g kg^{-1}

[1] 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.

Table 1. Cultural practices used in evaluation of two forage species and eight tillage systems for integrating winter-annual grazing with peanut production on a Dothan loamy sand in southeastern Alabama (2001–2003).

Species	Cultivar	Plant density	Planting date	Row spacing	Tillage	Grazing initiated	Grazing terminated
		kg ha^{-1}					
Oat	Harrison	160	20 Oct. 2000	17 cm	conventional	31 Jan. 2001	11 Apr. 2001
Ryegrass	Marshall	35	20 Oct. 2000	Broadcast	conventional	31 Jan. 2001	11 Apr. 2001
Peanut	Georgia Green	115	22 May 2001	91 cm	treatment variable	–	–
Oat	Mitchell	160	10 Nov. 2001	17 cm	no-till	22 Jan. 2002	15 Apr. 2002
Ryegrass	Marshall	35	10 Nov. 2001	Broadcast	no-till	22 Jan. 2002	15 Apr. 2002
Peanut	Georgia Green	115	26 May 2002	91 cm	treatment variable	–	–
Oat	Mitchell	160	18 Oct. 2002	17 cm	no-till	9 Jan. 2003	10 Apr. 2003
Ryegrass	Marshall	35	18 Oct. 2002	Broadcast	no-till	9 Jan. 2003	10 Apr. 2003
Peanut	Georgia Green	115	30 Apr. 2003	91 cm	treatment variable		

moisture basis before yield was determined. A 500-g subsample was removed from each plot at harvest and graded using standards established by the U.S. Federal State Inspection Service procedures for grading farmer-stock peanuts. Grades reported included sound mature kernels (SMK), sound split + SMK, and other kernels. These values were used to determine gross economic market value (\$392 Mg^{-1}) minus deductions for sound splits and damaged kernels. Net return value (\$ ha^{-1}) was calculated as the differences between gross economic market value minus total peanut production cost for each tillage system. Pasture and peanut cost values were estimated from each tillage system operation (including variable and fixed costs) assuming application of recommended management practices (Auburn University, 2004). For informational (non-statistical) comparisons between peanut following integrated winter-annual grazing vs. the conventional practice of annual peanut cropping, we used the mean yield of 'Georgia Green' from the AAES unirrigated peanut variety trials (2001–2003) at the location of our study (Wiregrass Research and Extension Center in Headland, AL) during the experiment (Alabama Agricultural Experimental Station, 2004). The soil type for the variety trials was the same as in our experiment. The tillage system used in the AAES peanut variety trials was chisel plus disk tillage without a cover crop, the standard practice by most producers in the region. For economics comparison analysis among forage species and tillage systems combination, we choose one conventional tillage (chisel + disk) and the three conservation tillage systems (strict no-till, in-row subsoil + no-till, and paratill + no-till) following oat.

Soil Water Content

Within the eight tillage and residue management systems tested, we selected four tillage systems (chisel plus disk, paratill plus disk, paratill plus no-till, and no-till) following both forage species, for more intensive data collection, including soil water content. A Tektronix 1502 C (Tektronix, Beaverton, OR) cable tester was used to measure soil water by time domain reflectrometry (Topp, 1980). Parallel-paired stainless steel rods, 300 mm by 6.4-mm diameter, were installed 10 cm away from the row in a trafficked and an untrafficked interrow, and connected to the cable tester with coaxial cables. Soil water content for this well-drained sandy loam ranges between 0.209 m^3 m^{-3} at field capacity to 0.059 m^3 m^{-3} at the permanent wilting point in the 30-cm depth, indicating an available water holding capacity of 0.150 m^3 m^{-3} in the upper 30 cm of soil (Quisenberry et al., 1987). Average volumetric water content was determined in the top 30-cm soil depth during peanut flowering in 2001 and 2002. In 2001, measurements were taken nine times, beginning 21 July [Day of Year (DOY) 202] and finishing 31 August (DOY 243). In 2002, six measures were taken, beginning on 26 July (DOY 207) and finishing 23 August (DOY 235). Row position (sub-subplots) was analyzed as an expansion of the original design (strip-plot) to a strip-split-plot model.

Stomatal Conductance

A Li-1600 steady state porometer (LI-COR Biosciences, Lincoln, NE) was used to measure peanut leaf stomatal conductance from the abaxial side of unshaded, uppermost fully expanded leaves in the canopy, in the same plots used for soil water content measurement. Measurements were taken in 2001 and 2002 from single leaves of four different plants per plot from the middle two rows of the plot. They were taken on uncloudy days from 1200 to 1500 h when solar radiation and plant transpiration were maximized. In 2001, measurements were taken during peanut flowering seven times, beginning 31 July (DOY 212) and ending 31 Aug. (DOY 243) and six times in 2002, beginning 27 July (DOY 208) and ending 20 Aug. (DOY 232).

Data Analysis

Forage species and tillage system effects on crop and soil indicators were evaluated using the appropriate strip-plot design using the PROC MIXED procedure of the Statistical Analysis System (Littell et al., 1996). Replication and its interactions were considered random effects and treatments as fixed effects. Analyses across years were made for peanut plant population and peanut yield, with year treated as a fixed effect to determine interactions involving years. Year × treatment interaction occurred for all variables. Therefore, data were additionally analyzed by year and treatment effects, and data are presented and discussed by year.

Soil water content and peanut leaf stomatal conductance were analyzed as a split plot in time; spatial correlation was accounted for each measurement day (Littell et al., 1996). Least square means comparisons were made using Fisher's protected least significant differences (LSD) with a significance level of $P \le 0.05$ established a priori.

Table 2. Peanut plant populations as affected by forage species and tillage system in an evaluation of two forages and eight tillage systems for integrating winter-annual grazing with peanut production on a Dothan loamy sand in southeastern Alabama (2001–2003).

Tillage system	Year 2001	Year 2002	Year 2003	Forage species† Oat	Forage species† Ryegrass
	Plants ha^{-1} (× 10^3)‡				
Moldboard + disk	94.4	81.2	125.0	102.6	97.8
Disk	91.4	74.0	110.1	94.2	89.4
Chisel + disk	92.2	75.5	119.2	99.8	91.4
In-row subsoil§ + disk	96.8	70.6	120.5	100.0	91.9
In-row subsoil + no-till	99.2	77.8	119.4	106.6	91.0
Paratill¶ + disk	93.6	69.2	117.7	97.3	90.0
Paratill + no-till	83.3	77.6	113.7	96.1	86.9
No-till	43.6	69.5	50.2	66.7	42.2
LS means	86.8	74.4	109.5	95.4	85.1
LSD (0.05) (tillage)	15.7	11.0	15.2		
LSD (0.05) (year)		5.1			
LSD (0.05) (forage × tillage)				6.9	
LSD (0.05) (forage)				6.0	

† Averaged over years.

‡ Multiply the reported values by this to obtain the actual numbers.

§ Noninversion deep tillage using a narrow-shanked subsoil in-row.

¶ Noninversion deep tillage using bent-leg subsoil.

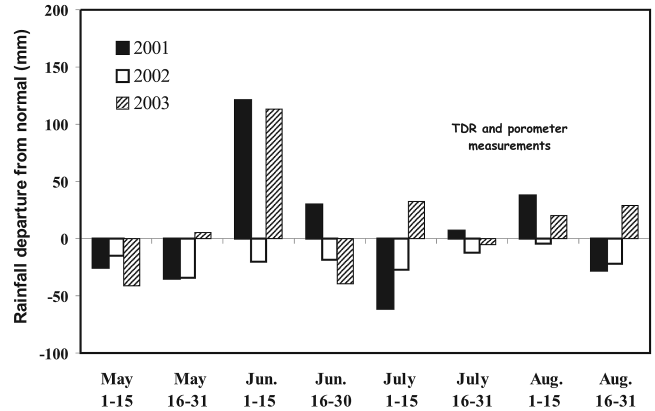

Fig. 1. Biweekly departure from long-term average rainfall (1938–2003) for the 3-yr study on a Dothan loamy sand in southeastern Alabama (2001–2003).

RESULTS AND DISCUSSION

Net Return Annual Grazing

Total DWG of annual grazing was 551 kg ha^{-1} for 81 d averaged over 3 yr. Studies with ryegrass grazing at three locations in Alabama established an average DWG of 6.5 kg ha^{-1} for stocker cattle in winter-early spring averaged over 122 d of grazing (Bransby et al., 1999). In our experiments, the Total DWG was 6.8 kg ha^{-1}. The high DWG ha^{-1} in our experiment, similar to the results reported by Bransby et al. (1999), demonstrates the high potential of this system. According to Auburn University Department of Agricultural Economics and Rural Sociology, total cost of winter-annual grazing in our experiment was \$193 ha^{-1} (does not include fences, water facilities, and land cost), leaving a net return from winter-annual grazing of ~\$185 to 200 ha^{-1}. Another criterion to compare systems for livestock production is cost kg^{-1} gain, which is dependent on input costs, production levels animal^{-1} ha^{-1}, and length of the grazing season. Ball et al. (2002) alleged that usually winter-annual pastures are comparatively expensive and must be well managed to produce profits. They reported cost kg^{-1} gain of ~\$0.55 to \$0.88. In our experiment, the cost kg^{-1} gain (averaged over years and forage species) was \$0.35. This demonstrates, under current economic conditions, that it is possible to achieve weight gains grazing oat or annual ryegrass profitably.

Peanut Population

Due to interactions (i.e., year × forage × tillage system), the results of plant populations are shown separately by year and by forage species (Table 2). Averaged over years and tillage systems, peanut plant stands following ryegrass were reduced compared with those following oat (95,400 vs. 85,100 plants ha^{-1}, $P \le 0.01$). Differences in plant stands associated with forage residue appeared to be partially due to mechanical problems which prevented good seed-to-soil contact, although no soil strength or soil water content measurements were taken at planting. Based on the dry matter production of both forage species (data not shown) at the end of the grazing period, ryegrass produced more dry matter, and N uptake was increased (45% greater N uptake with ryegrass than oat in the last month of grazing). When compared with oat, ryegrass may deplete more soil water before being terminated with herbicides, which could limit peanut stand establishment and seedling growth. Stand reduction might also be associated with allelopathic exudates from ryegrass residues. Burgos and Talbert (1996) found a reduction in cowpea (*Vigna unguiculata* L. Walp.) yield when ryegrass was used as a cover crop (Stirzaker and Bunn, 1996). Peanut plant stands were reduced by 32% in 2002 and 21% in 2001 compared to 2003 (Table 2). The year 2002 was a drier year compared with the average (Fig. 1), and consequently affected peanut stands and growth. Besides the dry conditions in the summer of 2002, the spring was warm, and both forages had the highest dry matter production among the three test years, which may have reduced soil moisture availability for the next cash crop (data not shown).

Strict no-till resulted in the lowest plant population in two of the 3 yr (2001 and 2003, $P \le 0.001$), and in 2002, the moldboard treatment had higher plant stands compared with strict no-till (81,200 vs. 69,500 plants ha^{-1}, $P \le 0.01$). Averaged over years, strict no-till in combination with ryegrass resulted in the the lowest plant stand (42,200 plant ha^{-1}), followed by strict no-till following oat (66,700 plants ha^{-1}). Deep tillage alleviated this problem in both forage species, but as mentioned previously, all tillage systems had better plant stands following oat. Comparing the two deep tillage systems in no-till (in-row subsoil or paratill), in-row subsoil resulted in better plant stands compared with paratill (98,800 vs. 91,500 plants ha^{-1}, $P \le 0.01$). The in-row subsoiling disrupts the seed zone before planting, while the paratill lifts the soil surface under the seed zone without disrupting it. We speculate that the paratill resulted in more surface soil compaction in the seeding zone compared with the in-row subsoiler, due to the lack of surface soil disruption. This may have reduced seed-soil contact and germination within the paratill treatment.

Table 3. Averaged soil volumetric water content and stomatal conductance during peanut flowering (2001–2002) as affected by row position, forage species, and selected tillage systems in an evaluation of two forages and eight tillage systems for integrating winter-annual grazing with peanut production on a Dothan loamy sand in southeastern Alabama.

	Soil water content		Stomatal conductance	
	2001	2002	2001	2002
	—— m^3 m^{-3}——		—mmol m^{-2} s^{-1}—	
Row position				
Untrafficked	0.110	0.096	–	–
Trafficked	0.133	0.114	–	–
LSD (0.05)	0.005	0.005	–	–
Forage species				
Oat	0.111	0.105	575	419
Ryegrass	0.132	0.105	560	408
LSD (0.05)	0.020	ns†	ns	ns
Tillage system				
Chisel + disk	0.120	0.105	592	427
Paratill‡ + disk	0.120	0.097	528	407
Paratill + no-till	0.125	0.099	583	412
No-till	–§	0.118	–	406
LSD (0.05) (tillage)	ns	0.017	ns	ns
LSD (0.05) (forage × tillage)	ns	ns	ns	ns

† ns, not significant at $P \le 0.05$.

‡ Noninversion deep tillage using bent-leg subsoil.

§ No data: Year 2001, soil water content and stomatal conductance was not measured in no-till system due to very compacted soil.

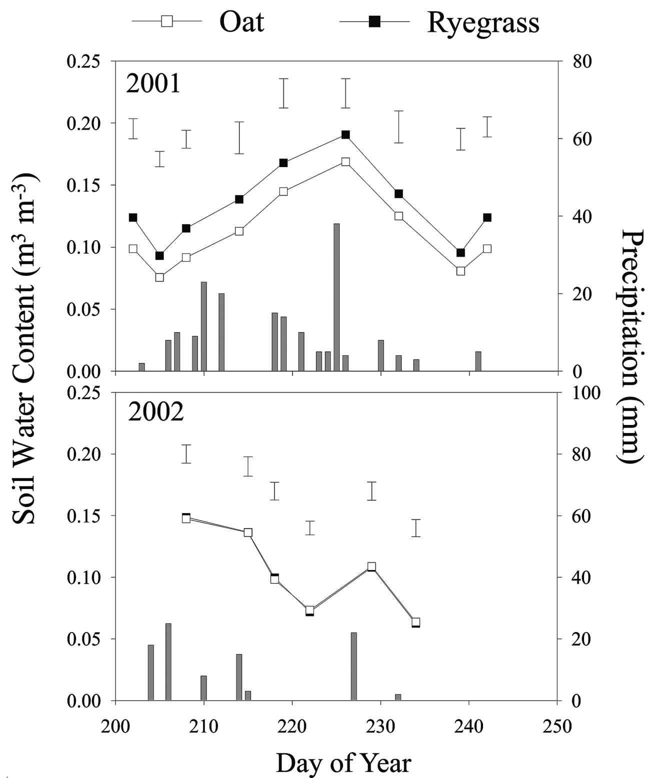

Fig. 2. Precipitation and volumetric soil water content during peanut flowering (averaged over row positions and tillage systems) as affected by forage species (2001–2002) in an evaluation of two forages and eight tillage systems for integrating winter-annual grazing with peanut production on a Dothan loamy sand in southeastern Alabama. Vertical bars indicate LSD (0.05).

Soil Water Content

Rainfall was below historic average during the 2002 peanut growing season (Fig. 1). On the other hand, rainfall in 2001 was 39% higher over the entire growing season compared with the average. Since no significant position × tillage system or position × forage species interactions occurred for soil water content (0–30 cm depth) for any of the years, data of positions are presented over tillage systems and forage species (Table 3). Trafficked locations presented higher soil water content than untrafficked locations (27% and 19% more soil water content in 2001 and 2002, respectively). These higher soil water contents at trafficked locations are consistent with expected differences in peanut rooting, that is, greater root growth and soil water extraction under the untrafficked locations and limited rooting and less soil water extraction in the trafficked location due to equipment traffic compaction (Reeves et al., 1992). In 2001, during peanut flowering, soil water content in treatments following oat was less than in treatments following ryegrass. (0.111 vs. 0.132 m^3 m^{-3}, $P \le 0.01$). These results suggest that ryegrass limited peanut root growth. We speculate that several factors were acting in concert to result in poorer peanut establishment and growth following ryegrass than oat: greater soil water depletion, greater nitrogen immobilization during residue decomposition, and allelopathic effects that consequently hinder peanut growth (Troughton, 1957; Weston, 1993). Four tillage systems were selected to determine soil water contents (chisel + disk, paratill + disk, paratill + no-till, and no-till) following winter-annual forages. In 2001, no significant differences were detected among tillage systems (strict no-till was not measured). Nevertheless, in 2002, strict no-till presented higher soil water contents compared with the other tillage systems, but paratill in no-till reduced soil water content compared with strict no-till (16% averaged over forages; $P \le 0.02$) (Table 3). Differential root growth under drought stress has been reported to be an adaptive mechanism in peanut (Boote and Ketring, 1990). We speculate that the lower soil water content (to the 30-cm depth) in subsoiled plots resulted from increased root growth. The extra benefits of increased rooting depth means that the plant has more access to soil water within the profile during drought periods and thus can better tolerate periods of water stress (Boote and Ketring, 1990).

Assuming that this sandy loam soil has 0.140 m^3 m^{-3} of available water capacity, following ryegrass in 2001, available water capacity ranged between 12 and 81% during the peanut flowering period (Quisenberry et al., 1987) (Fig. 2). Under soil water deficit (<33% of available water capacity), transpiration and stomatal conductance can be reduced (Boote and Ketring, 1990), resulting in less photosynthates for plant growth and yield. Consequently, we measured stomatal conductance as an indicator of plant water stress. In 2001, there were only two dates when available water capacity was <33%, indicating that water stress was not severe in 2001 (Boote and Ketring, 1990). However, in the dry year (2002), no differences were detected between the two forages (Fig. 3), but averaged over tillage systems and positions, only the first two dates had >33% of available soil water. This demonstrates that water stress was greater

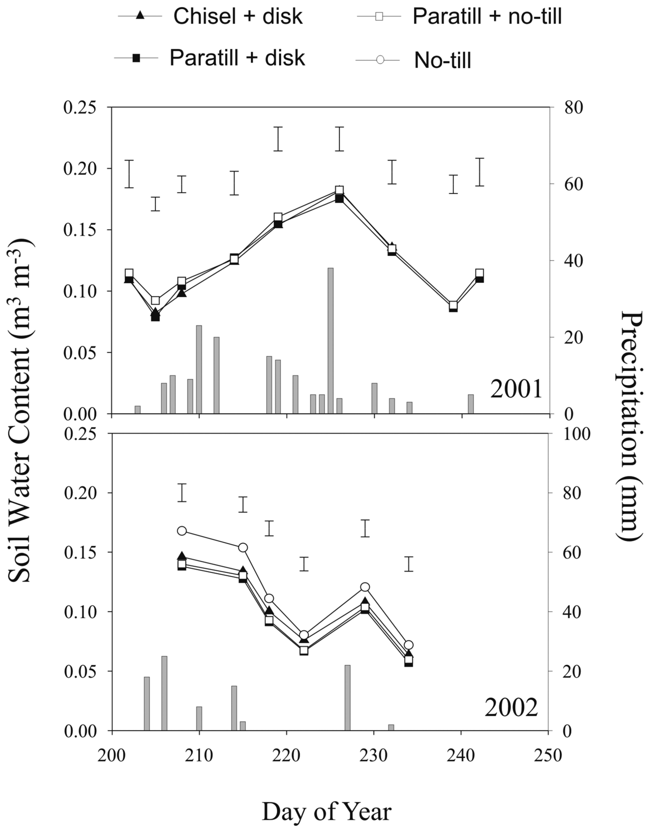

Fig. 3. Precipitation and volumetric soil water content during peanut flowering (averaged over row positions and forage species) as affected by selected tillage systems (2001–2002) in an evaluation of two forages and eight tillage systems for integrating winter-annual grazing with peanut production on a Dothan loamy sand in southeastern Alabama. Vertical bars indicate LSD (0.05).

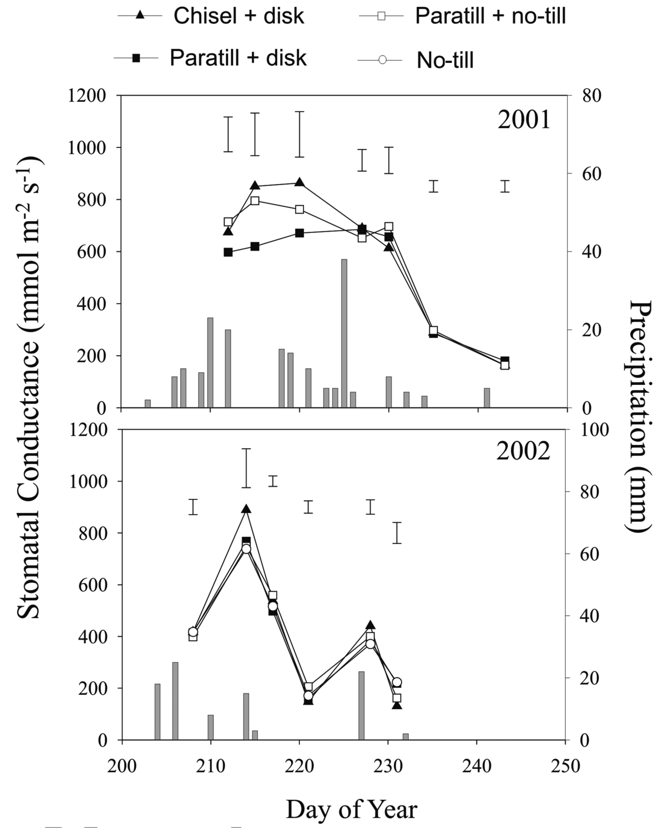

Fig. 4. Precipitation and stomatal conductance during peanut flowering (averaged over forage species) as affected by selected tillage systems (2001–2002) in an evaluation of two forages and eight tillage systems for integrating winter-annual grazing with peanut production on a Dothan loamy sand in southeastern Alabama. Stomatal conductance was not measured in no-till system in 2001. Vertical bars indicate LSD (0.05).

for this year. The soil water stress in 2002 was confirmed by lower peanut yield compared with 2001.

Although variations during the measurement periods were noted in 2001 (due to different rainfall and physiological stages of peanut in 2001), soil water content was not affected by tillage systems (only one date was significant) (Fig. 3). In 2002, strict no-till presented significantly higher soil water content on two of the six measurement days. The pattern was similar for the other four measurements periods.

Stomatal Conductance

Peanut leaf stomatal conductance was measured in the same tillage systems that were selected for soil water content measurements, to relate plant water stress to soil water changes impacted by treatments. Stomatal conductance decreased in all tillage systems with an increase in soil water deficit, and this effect was more pronounced in 2002 (Fig. 3 and 4). Several studies have shown decreased stomatal conductance with increased water deficit in irrigation experiments, increasing canopy temperature, which results in reduced assimilation rates and peanut yields (Pallas et al., 1979; Nageswara Rao et al., 1988). All tillage systems had similar stomatal conductance except for one date (DOY 213) in 2001. Paratill + disk had a slightly lower stomatal conductance compared with the other tillage systems between DOY 210 to 220 in 2001 (around 10–20 d initiated the flowering period). A similar trend was observed with soil water content for this tillage system. According to rain data, this period (DOY 210–220) was very wet (75 mm). We assumed that paratill + disk promoted more root growth than other tillage treatments, which lead to more soil water extraction, resulting in lower turgor potentials at the end of the flowering period under dry conditions (only 21 mm in the last 17 d of flowering period). We also attributed the lowered leaf stomatal conductance to larger plant size, with greater soil water extraction and poorer rationing of water during the period than smaller plants with less water demand.

Averaged over the measurement period, there was no difference between forage species and tillage systems for stomatal conductance in either year (Table 3). Our results are consistent with those of Bennet et al. (1984). Those authors concluded that factors such as the capacity to maintain relatively high tissue water status and sustain development plasticity through periods of low soil water availability are partly responsible for peanut's drought resistance. Stomatal conductance was higher in 2001 compared with 2002. The 2002 growing season was drier than average, resulting in less available soil water. Data in Table 4 confirmed the difference between these 2 yr for peanut yield, where 2002 had lower yields compared with 2001 (4.26 vs. 3.65 Mg ha^{-1}, $P \le 0.01$). However, more precipitation (64%) in 2001 compared with 2002 only increased peanut yield by 17%. Our studies agree with those that have shown the peanut's reputed drought tolerance (e.g., deeper rooting and greater

Table 4. Peanut yields as affected by forage species and tillage systems in an evaluation of two forages and eight tillage systems for integrating winter-annual grazing with peanut production on a Dothan loamy sand in southeastern Alabama (2001–2003).

Main effect	Peanut yield 2001	2002		2003	LS means
	Mg ha^{-1}				
Forage species					
Oat	4.66	4.05		3.69	4.13
Ryegrass	3.86	3.24		3.11	3.40
LS means	4.26	3.65		3.40	
LSD (0.05) (forage)	0.32	0.33		0.34	0.22
LSD (0.05) (year)		0.37			
Tillage system		Oat	Ryegrass		
Moldboard + disk	4.64	3.24	3.34	4.00	3.98
Disk	4.63	4.30	3.19	3.24	3.87
Chisel + disk	4.56	4.16	3.36	3.47	3.93
In-row subsoil† + disk	4.72	3.53	3.36	3.60	3.97
In-row subsoil + no-till	4.61	4.59	3.77	3.62	4.13
Paratill‡ + disk	4.68	4.10	3.37	3.90	4.10
Paratill + no-till	4.31	4.30	3.51	3.30	3.84
No-till	1.90	3.88	2.02	2.03	2.29
LSD (0.05) (tillage)	0.72			0.80	0.60
LSD (0.05) (forage × tillage)	ns§	0.60		ns	

† Noninversion deep tillage using a narrow-shanked subsoiler in-row.

‡ Noninversion deep tillage using bent-leg subsoil.

§ ns, not significant at $P \leq 0.05$.

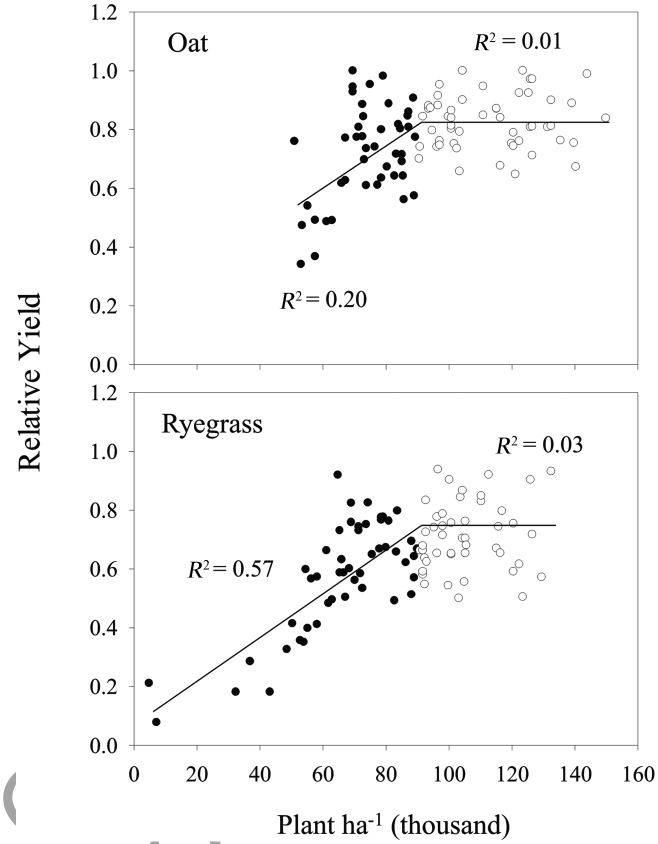

Fig. 5. Relationship between relative yield and peanut plant populations as affected by forage species (2001–2003) in an evaluation of two forages and eight tillage systems for integrating winter-annual grazing with peanut production on a Dothan loamy sand in southeastern Alabama (2001–2003). R^2 indicates coefficient of determination for the two ranges of plant population (0–85,000 and 85,000–150,000 plants).

relative flexibility in time of flowering and fruiting) (Allen et al., 1976; Pandey et al., 1984; Boote and Ketring, 1990).

Peanut Yield and Economic Return

Peanut yield averaged 4.26, 3.65, and 3.40 Mg ha^{-1} for 2001, 2002, and 2003, respectively. Even though there were differences between years, no forage species × year interaction affected yield (Table 4). The greatest peanut yields were obtained following oat (4.13 vs. 3.40 Mg ha^{-1} following oat and ryegrass, respectively; $P \leq 0.01$). As mentioned previously, plant density was affected by forage species (12% higher plant populations following oat compared with ryegrass), and consequently forage species impacted peanut yield (21% higher yield following oat compared to ryegrass). Regression analysis between plant population and relative peanut yield for the 3 yr of study showed a good relationship up to a population of 85,000 plants ha^{-1} (Fig. 5). Plant population explained 57% of the variation in peanut yield following ryegrass, up to 85,000 plants ha^{-1}, although only 20% of the peanut yield variation was explained by plant population following oat. One reason for this lower coefficient of determination (R^2) could be the narrow range of peanut plant populations following oat. Above 85,000 plants ha^{-1}, there was no relationship between peanut yield and plant population regardless of forage species. Considering that the recommended plant density is around 130,000 plants ha^{-1}, all plant stands were below recommended levels, but we found no relationship between plant density and yield above 85,000 plants ha^{-1}.

Peanut yields were affected by forage species and tillage system interactions only in 2002. Moldboard was the only tillage system where peanut yield was equal between the two forages species (3.24 and 3.34 Mg ha^{-1} for oat and ryegrass, respectively). The other seven tillage systems showed higher peanut yields following oat compared with following ryegrass. An interaction between year × tillage system occurred for peanut yields (Table 4). In 2001 and 2003, no-till systems had lower peanut yields compared with the other seven tillage systems (1.90 vs. 4.59, and 2.03 vs. 3.59 Mg ha^{-1} for 2001 and 2003, respectively). No differences were detected among the three conventional tillage systems vs. no-tillage with noninversion deep tillage (either paratill or in-row subsoil) for the normal precipitation years (2001 and 2003). However, in the dry year (2002), no-till with deep tillage (in-row subsoil or paratill) had a better peanut yield (12%, $P \leq 0.01$) compared with the other five conventional tillage systems (with or without deep tillage). These results are consistent with those found by Marois and Wright (2003), who reported that using strip-tillage with residue covering promoted greater peanut yield compared with conventional tillage in an exceptionally dry year.

When averaged over years, strict no-till (2.29 Mg ha^{-1} peanut yield averaged over forage species) resulted in the lowest peanut yields (42% less than the overall mean). Data averaged over years show that within no-tillage systems, peanut yields were greater with in row subsoil than paratill (4.13 vs. 3.84 Mg ha^{-1}, $P \leq 0.07$), especially following ryegrass compared with oat (3.78 vs. 3.33 Mg ha^{-1} following ryegrass, $P \leq 0.05$, and 4.50 vs. 4.34 Mg ha^{-1} following oat, $P \leq 0.15$, for in-row subsoil and paratill, respectively) (data not shown). Deep tillage

Table 5. Effect of four tillage system on peanut yield and net return for peanut production and annual return added integration of oat grazing comparing with the variety trials without irrigation in an evaluation of two forages and eight tillage systems for integrating winter-annual grazing with peanut production on a Dothan loamy sand in southeastern Alabama (2001–2003), averaged over three years.

Tillage system	Peanut production†				Net return	
	Yield	Gross value‡	Cost§	Net return	Annual grazing	Total annual system
	Mg ha^{-1}	USD ha^{-1}				
Chisel + disk	4.30	1686	1500	186	185	371
In-row subsoil + no-till	4.50	1764	1487	277	185	462
Paratill + no-till	4.34	1700	1482	218	185	403
No-till	3.00	1176	1320	−144	185	41
Variety trials¶	4.11	1611	1490#	121	0	121

† Peanut yield taken from following oat species.

‡ Gross value using peanut market loan program ($392 Mg ha^{-1}).

§ Included fixed and variable costs for each tillage system.

¶ Yield was taken from Georgia Green in the nonirrigated peanut variety trials for the same period (2001–2003) at Wiregrass Station.

In the Variety trials: chisel + disk was used for the cost analysis.

in no-till systems was more important following ryegrass than oats. These results agree with those of Oyer and Touchton (1988), who found advantages to previous deep tillage in a no-till system in coastal plain soils with root-restricting soil layers (24% increase in peanut yield averaged over 2 yr), but no advantages of in-row subsoil in conventional tillage systems.

Averaged over 3 yr, peanut following oat resulted in a higher percentage of SMK than following ryegrass (69.8 vs. 67.2, $P \leq 0.01$) and strict no–till presented the lowest SMK among tillage systems (64.9 vs. 69.0% for no-till when averaged over seven tillage systems) possibly due to soil compaction (data not shown) (Grichar, 1998).

In the nonirrigated peanut variety trials at this Experiment Station, Georgia Green averaged 4.11 Mg ha^{-1} for the 2001–2003 period. This, compared with winter forage by tillage system combinations (in-row subsoil + no-till = 4.13 Mg ha^{-1}) in our study, demonstrated that double-cropping peanut following grazing is an excellent way for peanut producers to diversify operations and improve income (Table 5). This indicates that the inclusion of winter-annual grazing with oat did not decrease peanut yield in the Coastal Plain and can provide producers extra revenue in winter months. In-row subsoil presented the higher annual net return ($462 ha^{-1}) and close to half of total net return came from winter-annual grazing ($185 ha^{-1}).

Our study was conducted in a location that was conventionally tilled for the previous century. Benefits from no-till management regularly require years to express its full potential for improving soil organic carbon and soil productivity (Dick et al., 1991). Thus, the benefits of using noninversion deep tillage in a no-tillage system following winter-grazing on soil carbon storage and soil quality indicators should increase with time.

CONCLUSIONS

Our study shows that integration of winter-annual grazing in peanut production can enhance profitability for Southeastern producers. Data suggested that peanut following oat improved plant populations and increased rooting and soil water extraction compared with peanut following annual ryegrass (possibly associated with more N uptake later in the cycle, root restriction, and some allelopathic effect by ryegrass). We found no clear effect of forage species or tillage system on peanut leaf stomatal conductance. Strict no-till resulted in lower plant populations, reduced soil water extraction, and lowered peanut yields (47, 15, and 42%, respectively) when compared with the other seven tillage systems. Oat appears to be a better choice than ryegrass for peanut grown following winter-annual grazing, and deep tillage was necessary to maximize yields in no-tillage. Deep tillage in conventional surface tillage systems did not increase peanut yield. Within no-tillage systems, peanut yields were greater with in-row subsoil using the narrow-shanked implement compared to paratill (4.13 vs. 3.84 Mg ha^{-1}, respectively). Oat, together with in-row subsoil for peanut production, had the greatest total annual net return [$462 ha^{-1}, and net returns from animal production represented 40% of the total return ($185 ha^{-1})]. In conclusion, integrating winter-annual grazing with peanut using noninversion deep tillage in conservation tillage systems can increase profitability for producers without sacrificing peanut yields. We believe that integrating winter-annual grazing with peanut production can be an effective means to help Southern farmers increase income.

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