Crop Response to Rotation and Tillage in Peanut-Based Cropping Systems

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ABSTRACT

Production of peanut (*Arachis hypogaea* L.) in reduced tillage systems has increased in the United States during the past decade. However, interactions of tillage system and crop rotation have not been thoroughly investigated for large-seeded, Virginia market type peanut. Research was conducted at two locations in North Carolina during 1999 to 2006 to compare yield of corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), and peanut in different rotations planted in conventional and reduced tillage. Crop rotation affected peanut yield but did not affect corn or cotton yield. Increasing the number of times corn, cotton, or a combination of these crops were planted between peanut increased peanut yields. Tillage affected cotton and peanut yield but not in every year or at both locations. Yield was similar in conventional and reduced tillage in 8 of 10 comparisons (cotton) and 6 of 8 comparisons (peanut). Crop rotation and tillage did not interact for visual estimates of plant condition of peanut as a result of disease, soil parasitic nematode populations when peanut was planted during the final year of the experiment, crop yield, cumulative net return over the duration of the experiment, or bulk density in the pegging zone during the final year of the experiment. These data suggest that variation in response to rotation and tillage should be expected based on the crop and edaphic and environmental conditions. However, response to rotation and tillage most likely will be independent.

The majority of peanut in the United States has historically been planted in conventional tillage (Sholar et al., 1995). However, the percentage of peanut hectares in reduced or conservation tillage has increased during the past decade in the southern United States (Denton and Tyler, 2002). Farmers in North Carolina reported an increase in reduced tillage production from 10% during 1998 to 23% during 2005 (Jordan and Johnson, 2006). Growers in the southern United States have also adopted reduced tillage for cotton and corn (Denton and Tyler, 2002).

Research has shown considerable variation in peanut response to tillage (Grichar, 1998; Jordan et al., 2001, 2003; Wright and Porter, 1995). Higher yields in reduced tillage have been associated with lower incidence of tomato spotted wilt virus (TSWV), a *Tospovirus*, vectored by thrips (*Frankliniella* spp.) (Johnson et al., 2001; Marios and Wright, 2003). Similar response of Virginia market type peanut to conventional and reduced tillage was observed regardless of fertilization practices or cultivar selection (Jordan et al., 2001, 2003). However, lower peanut yield was often noted in reduced tillage when Virginia market type peanut was planted on fine-textured soils compared with coarse-textured soils (Jordan et al., 2003; Jordan and Johnson, 2006). Inconsistent response to reduced tillage in runner market type production has also been reported (Monfert et al., 2004).

The value of increasing the number of years nonleguminous crops are planted between peanut to reduce pests and maintain or increase peanut yield is well documented (Jordan et al., 2002; Lamb et al., 1993; Rodriguez-Kabana et al., 1987; Rodriguez-Kabana and Touchton, 1984). Crops can respond differently to tillage when grown in different cropping systems (Katsvairo and Cox, 2000; Porter et al., 1997; Raimbault and Vyn, 1991). Corn and cotton yield is often similar when planted in reduced tillage or conventional tillage (Johnson et al., 2001), although variable response to tillage and crop rotation and the interaction of these cultural practices have been reported (Balkom et al., 2006; Boquet et al., 2004; Burmester et al., 2002; Reddy et al., 2006; Vetsh and Randall, 2002; Vetsh et al., 2007).

Fewer diseases affect corn and cotton compared with peanut (Ayers et al., 1989; Lamb et al., 1993; Rodriguez-Kabana et al., 1987; Rodriguez-Kabana and Touchton, 1984; Sidebottom and Beute, 1989). Crop rotation can affect pest development and crop yield. Planting a diversity of crops in rotation can minimize disease and parasitic nematode populations and increase crop yield (Hague and Overstreet, 2002; Rodriguez-Kabana et al., 1987; Rodriguez-Kabana and Touchton, 1984). However, the economic value of each crop in the rotation must be considered when formulating cropping systems (Godsey et al., 2007; Grandy et al., 2006; Sholar et al., 1995).

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Abbreviations: CBR, Cylindrocladium black rot; CNR, cumulative net return; PCR, plant condition rating; TSWV, *tomato spotted wilt virus*.

Soil chemical and physical properties often change as a result of alterations in tillage practices. Lower soil bulk density is often observed in reduced tillage compared with conventional tillage when reduced tillage practices have been implemented for multiple years (Naderman et al., 2004; Overstreet et al., 2004). Rowland et al. (2007) reported interactions among irrigation and tillage for peanut pod production. Fewer pods per plant were produced in reduced tillage compared with conventional tillage in subsurface irrigation.

Interactions of tillage and cropping systems have not been thoroughly evaluated for Virginia market type peanut. In runner market type peanut production, pod yield often is similar when peanut is planted in conventional and reduced tillage (Marios and Wright, 2003). Determining if crop rotation influences yield response of Virginia market type peanut to reduced tillage would be beneficial in defining when reduced tillage could be successfully implemented in peanut-based cropping systems.

The objectives of this research were to determine effects of tillage and cropping system on (i) yield of corn, cotton, and peanut; (ii) development of disease in peanut and plant parasitic nematodes; (iii) cumulative net return; and (iv) bulk density in the pegging zone.

MATERIALS AND METHODS

Experiments were conducted in North Carolina at the Peanut Belt Research Station located near Lewiston–Woodville on a Norfolk sandy loam (fine-loamy, siliceous, thermic, Typic Paleudults) and the Upper Coastal Plain Research Station located near Rocky Mount on a Goldsboro loamy sand (fine-loamy, siliceous, thermic, Aquic Paleudalts). Soil pH and organic matter over the duration of the experiment at Lewiston–Woodville was 5.9 to 6.2 and 9 to 11 g kg^{-1}, respectively. Soil pH ranged from 5.7 to 6.4 and organic matter 8 to 13 g kg^{-1} at Rocky Mount. Plot size was 12 rows (91-cm spacing) by 15 m (Lewiston–Woodville) or 8 rows (91-cm spacing) by 20 m (Rocky Mount).

Crops in the four rotations at Lewiston–Woodville were corn, cotton, and peanut, whereas only cotton and peanut were included at Rocky Mount (Table 1). The amount of rainfall for each month from April through September during all years of the experiment is presented in Table 2 (State Climate Office of North Carolina, Raleigh, NC). Corn hybrids at Lewiston–Woodville included Dekalb 714 (1999), Pioneer 3223 (2001), Dekalb 697 (2003), and Dekalb 6971 RR (2005). Cotton cultivars at Lewiston–Woodville were Suregrow 125 (1999 and 2000), Suregrow 747 (2001), Deltapine 751 (2003), Fiber Max 959 (2004), and Deltapine 424 BGRR (2005).

Table 1. Cropping systems including corn, cotton, and peanut evaluated in conventional and reduced tillage systems in North Carolina at Lewiston–Woodville and Rocky Mount.

1999	2000	2001	2002	2003	2004	2005	2006
			Lewiston–Woodville				
cotton	peanut	cotton	peanut	cotton	peanut	cotton	peanut
corn	peanut	corn	peanut	corn	peanut	corn	peanut
cotton	cotton	cotton	peanut	cotton	cotton	cotton	peanut
cotton	cotton	corn	peanut	cotton	cotton	corn	peanut
			Rocky Mount				
–	peanut	cotton	peanut	cotton	peanut	cotton	peanut
–	cotton	cotton	peanut	cotton	peanut	cotton	peanut

Cotton cultivars at Rocky Mount were Stoneville 474 during 2000, 2001, and 2003 with Deltapine 488BGRR planted during 2005. The peanut Virginia market type cultivar NC 12C was planted at Lewiston–Woodville during all years. This cultivar is susceptible to TSWV but offers partial resistance to Cylindrocladium black rot (CBR) (caused by *Cylindrocladium parasiticum*) (Shew, 2007). The Virginia market type cultivar NC-V 11 was planted at Rocky Mount during 2000 and 2002 while the Virginia market type cultivar VA 98R was planted at this location during 2004 and 2006. The cultivar NC-V 11 but not VA 98R is partially resistant to TSWV (Shew, 2007). Both of these cultivars are susceptible to CBR (Shew, 2007).

Within each cropping system, conventional tillage and reduced tillage were compared. Conventional tillage consisted of disking twice, field cultivating once, and simultaneously subsoiling and bedding. Reduced tillage consisted of strip tilling a 40-cm wide band on 91-cm rows into residue from the previous crop at Rocky Mount or in a killed wheat (*Triticum aestivum* L.) cover crop at Lewiston–Woodville using strip tillage implements consisting of two sets of coulters and basket attachments following in-row subsoiling (KMC Manufacturing). Depth of subsoiling was 30 to 40 cm with crops planted within 1 wk following reduced tillage or bedding. Existing winter vegetation and emerged summer weeds were controlled using sequential applications of glyphosate [*N*-(phosphonomethyl)glycine] within 2 wk before planting. Seedbeds were weed free at the time of planting. Disease, insect, and in-season weed management inputs were held constant over the entire test area at each location for each crop and were based on North Carolina Cooperative Extension Service recommendations (Anonymous, 2008a, 2008b, 2008c). Terbufos {*S*-[[(1,1-dimethylethyl)thio]methyl] *O*,*O*-diethyl phosphorodithioate} at 1.1 kg a.i. ha^{-1} was applied in the seed furrow to corn. Aldicarb [2-methyl-2-(methylthio)propionaldehyde *O*-methylcarbamoloxime] at 0.84 kg a.i. ha^{-1} and 1.1 kg ha^{-1} was applied in the seed furrow with cotton and peanut, respectively.

The experimental design at Lewiston–Woodville was a split plot with crop rotation serving as the whole plot unit and tillage system serving as subplot units. This design was established

Table 2. Monthly rainfall from April through September in North Carolina at Lewiston–Woodville and Rocky Mount during 1999–2006.†

Month	1999	2000	2001	2002	2003	2004	2005	2006
				mm				
				Lewiston–Woodville				
April	24	63	47	45	159	49	73	103
May	49	93	51	44	145	104	116	125
June	64	114	262	65	113	123	55	226
July	73	89	109	102	163	143	123	203
August	94	109	78	128	117	284	83	86
September	395	142	67	112	224	83	49	187
Total	699	610	614	496	921	786	499	930
				Rocky Mount				
April	55	64	41	11	137	59	79	73
May	46	73	85	30	141	98	115	112
June	42	96	136	77	63	146	136	259
July	87	117	160	188	128	42	66	180
August	55	172	129	218	128	240	68	101
September	807	133	55	93	194	84	44	154
Total	1092	655	606	617	791	669	508	879

† Data provided by the State Climate Office of North Carolina.

Table 3. *F* statistic from analyses of variance for crop yield and cumulative net return in corn, cotton, and peanut rotations in conventional and reduced tillage systems at Lewiston–Woodville, NC.†

Treatment factors	Crop yield														
	1999		2000		2001		2002	2003		2004		2005		2006	CNR
	CR	CT	CT	PN	CT	CR	PN	CT	CR	PN	CT	CR	CT	PN	1999–2006
Rotation	–	–	1.2	0.9	0.6	5.8	6.5**	0.3	–	3.6	0.2	1.5	0.2	20.6**	10.8**
Tillage	2.1	6.9*	5.3	0.1	0.3	0.2	4.1*	0.1	1.1	2.6	0.3	2.2	1.0	0.4	5.6*
Rotation × Tillage	–	–	2.5	0.1	5.7	0.9	1.7	0.4	–	1.4	0.3	1.0	1.1	3.0	0.2

* Significant at $P = 0.01$ to 0.05.

** Significant at $P < 0.01$.

† CNR, cumulative net return; CR, corn; CT, cotton; PN, peanut.

Table 4. *F* statistic from analyses of variance for crop yield and cumulative net return in cotton and peanut rotations in conventional and reduced tillage systems at Rocky Mount, NC.†

Treatment factors	Crop yield								
	2000		2001	2002	2003	2004	2005	2006	CNR
	PN	CT	CT	PN	CT	PN	CT	PN	2000–2006
Rotation	–	–	0.4	3.7	0.1	4.9*	1.0	0.1	0.2
Tillage	1.6	2.1	1.9	2.9	0.2	0.3	17.5**	11.7**	2.8
Rotation × Tillage	–	–	0.1	3.8	0.1	1.2	0.1	0.1	1.0

* Significant at $P = 0.01$ to 0.05.

** Significant at $P < 0.01$.

† CNR, cumulative net return; CR, corn; CT, cotton; PN, peanut.

to allow more efficient management of crops throughout the growing season and to minimize pesticide drift to susceptible crops. A randomized complete block design was used at Rocky Mount. Subplots were replicated four times at both locations.

Yield was determined for each crop during all years. Cotton lint yield was determined based on seed cotton yield assuming 33% lint turnout. Yield of corn and peanut were adjusted to final moistures of 130 and 80 g kg^{-1}, respectively. Within 2 wk of peanut harvest during 2002 and 2006, ratings of visual estimates of plant condition (PCR) for peanut were recorded for each rotation and tillage combination on a scale of 0 to 100%, where 0 = no disease symptoms and 100 = the entire plot was expressing symptoms of wilting, yellowing, canopy defoliation, or plant death. The visual estimates reflected effects of CBR and TSWV (Shew, 2007). Visual estimates of disease were not recorded for corn or cotton at either location during any year these crops were planted. At both locations during 2006, 15 soil cores were collected from a depth of 0 to 12 cm on each of the two harvest rows and were combined into one sample within 2 wk before digging and vine inversion. Populations of plant parasitic nematodes, primarily root knot nematode (*Meloidogyne arenaria* and *M. hapla*) at Lewiston–Woodville, and lesion (*Pratylenchus* spp.), ring (*Mesociconema* spp.), spiral (*Helicotylenchus* spp.), and sting (*Belonolaimus longicavdatus*) at Rocky Mount, in 500-cm^3 soil were assayed by the North Carolina Department of Agriculture and Consumer Service. Samples were assayed by a combination of elutriation (Byrd et al., 1976) and centrifugation (Jenkins, 1964). Data were transformed to the log of nematode population before analyses.

Cumulative net return (CNR) to overhead, risk, and management was calculated for each crop during each year using budgets prepared by the North Carolina Cooperative Extension Service for corn (R.E. Heiniger, personal communication, North Carolina Coop. Ext. Service, Raleigh), cotton (Brown, 2007), and peanut (Bullen and Jordan, 2007). Net return was calculated as the product of crop yield (kg ha^{-1}) and prices of \$0.12 kg^{-1} (corn), \$1.32 kg^{-1} (cotton), and \$0.53 kg^{-1} (peanut) less fixed and variable costs for each tillage system. Peanut price reflected the average price of Virginia market type peanut during 2007 (R.M. Sutter, North Carolina Peanut Growers Assoc., Nashville, NC). Prices for corn and cotton were in the range of prices for these commodities during the duration of the experiment. The same price for each commodity was used throughout the duration of the experiment. Costs of production for corn were \$687 ha^{-1} and \$647 ha^{-1} for conventional and reduced tillage systems, respectively. Costs for these respective tillage systems in cotton were \$1272 ha^{-1} and \$1242 ha^{-1}. For peanut, cost of production in conventional tillage was \$1793 ha^{-1} while cost of production in reduced tillage was \$1739 ha^{-1}. Cumulative net return (CNR) in \$ ha^{-1} over the duration of the experiment was calculated for each combination of tillage and rotation system.

A soil sample in the pegging zone at a depth of 0 to 12 cm was removed from each combination of rotation and tillage within 2 wk before digging peanut during 2006 to determine bulk density (g cm^{-3}). The sample was removed 10 cm from the planted row of peanut using a probe with a diameter of 6.5 cm. Samples were oven-dried at a temperature of 100°C for 3 d before determining soil mass.

Data for crop yield, PCR for peanut, soil population of plant parasitic nematodes by species, CNR, and bulk density were subjected to analysis of variance appropriate for the factorial treatment arrangement including crop rotation and tillage systems. In some instances for crop yield, rotation was not a component of the analysis within a given year because of the rotation sequence. In these cases, yield response to tillage was compared. Means for significant main effects and interactions were separated using Fisher's Protected LSD Test at $P \le 0.05$. All analyses were conducted with the general linear model procedure of SAS v 9.1 (SAS Inst., Cary, NC).

RESULTS AND DISCUSSION

Crop Yield

Main effects of crop rotation and tillage system were significant during some years and for certain crops within a year at both Lewiston–Woodville and Rocky Mount (Tables 3 and 4). However, the interaction of crop rotation and tillage system for crop yield was not significant for any year and crop combination at either location (Tables 3 and 4). Data for main effects of crop rotation and tillage system for all crops during all years are presented regardless of significance of the main effect.

At Lewiston–Woodville, the main effect of crop rotation was significant for peanut yield during both years (2002 and 2006) when peanut was grown in all rotations (Table 3). In contrast, corn and cotton yield was not affected by crop rotation in any year (Table 3). Peanut yield was lower during 2002 and 2006 when only 1 yr of corn or cotton preceded peanut crops compared with 3 yr of cotton or the rotation of cotton-cotton-corn preceding peanut crops at Lewiston–Woodville in 1999 (Table 5). At Rocky Mount, crop rotation affected peanut yield during 2004 but not during 2002 or 2006 (Table 4). Peanut yield at this location was higher during 2004 when 2 yr of cotton preceded peanut crops rather than just 1 yr (Table 6). Results from these experiments support previous research demonstrating that increasing the number of years corn, cotton, or a combination of corn and cotton are planted between peanut increased peanut yield (Ayers et al., 1989; Lamb et al., 1993; Jordan et al., 2001; Rodriguez-Kabana et al., 1987; Rodriguez-Kabana and Touchton, 1984; Sidebottom and Beute, 1989). In contrast to peanut, rotation did not affect corn or cotton yield. Although research indicates that corn rotated with leguminous crops such as soybean [*Glycine max* (L.) Merr.] increase yield (Katsvairo and Cox, 2000), it is possible that the length of rotation, at the most 3 yr of cotton or cotton-cotton-corn, separated by peanut was sufficient to maintain optimum yield of these crops in our experiment. The major focus of this research was to determine effects of rotation and tillage on peanut, and therefore a different sequence of crop rotations most likely would be needed to determine rotation effects on corn and cotton.

Peanut yield differed when comparing tillage systems in 1 of 4 yr (Lewiston–Woodville) and in 1 of 4 yr (Rocky Mount) (Tables 5 and 6). At Lewiston–Woodville, peanut yield in reduced tillage exceeded yield in conventional tillage in 2002. Conversely, peanut yield was higher at Rocky Mount in conventional tillage compared with reduced tillage in 2002. Previous research (Jordan and Johnson, 2006) suggests that lower peanut yield in reduced tillage systems is often associated with production on fine-textured soils compared with coarse-textured soils. Soil at Rocky Mount, where peanut yield was lower in the reduced tillage system in 2006, was a Goldsboro loamy sand, whereas at Lewiston–Woodville where yield in reduced tillage exceeded conventional tillage was a Norfolk sandy loam. However, the interaction of tillage systems and effects of TSWV may have contributed to a positive response to reduced tillage at Lewiston–Woodville (Brandenburg, 2007). A clear explanation of differences in crop response to tillage was not forthcoming, especially for cotton.

Differences in yield were noted for cotton in 1 of 6 yr (Lewiston–Woodville) or 1 of 4 yr (Rocky Mount) when comparing tillage systems (Tables 6 and 7). Yield was lower in reduced tillage compared with conventional tillage at Lewiston–Woodville, whereas the opposite was the case at Rocky Mount. Corn yield in these two tillage systems

Table 5. Influence of rotation and tillage on peanut yield at Lewiston–Woodville, NC.†

Treatment factor	Peanut yield 2000	2002	2004	2006
	kg ha^{-1}			
Crop rotation (1999–2006)				
CT-PN (4 cycles)	3800 a‡	2460 b	4590 a	3410 b
CR-PN (4 cycles)	3300 a	2280 b	5340 a	3740 b
CT-CT-CT-PN (2 cycles)	–	3100 a	–	5030 a
CT-CT-CR-PN (2 cycles)	–	2930 a	–	5320 a
Tillage system§				
Conventional	3560 a	2640 b	4680 a	4410 a
Reduced	3540 a	2840 a	5250 a	4340 a

† CR, corn; CT, cotton; PN, peanut.

‡ Means within a treatment factor, crop, and year combination followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$.

§ Conventional tillage consisted of disking twice, field cultivating once, and simultaneously subsoiling and bedding. Reduced tillage consisted of strip tilling a 40-cm wide band on 91-cm rows using strip tillage implements consisting of two sets of coulters and basket attachments following in-row subsoiling. Depth of subsoiling was 30 to 40 cm with crops planted within 1 wk following reduced tillage or bedding.

Table 6. Influence of rotation and tillage on cotton and peanut yield at Rocky Mount, NC.†

	Crop yield							
	2000		2001	2002	2003	2004	2005	2006
Treatment factor	PN	CT	CT	PN	CT	PN	CT	PN
	kg ha^{-1}							
Crop rotation (2000–2006)								
CT-CT-PN-CT-PN-CT-PN	–	1000	940 a‡	3890 a	1220 a	3310 a	500 a	3410 a
PN-CT-PN-CT-PN-CT-PN	4070	–	920 a	4310 a	1220 a	2800 b	490 a	3440 a
Tillage system§								
Conventional	4220 a	1030 a	960 a	4290 a	1230 a	3120 a	450 b	3970 a
Reduced tillage	3910 a	970 a	910 a	3910 a	1210 a	2990 a	540 a	2880 b

† CT, cotton; PN, peanut.

‡ Means within a treatment factor, crop, and year combination followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$. Data for each treatment factor are pooled over levels of the other treatment factor.

§ Conventional tillage consisted of disking twice, field cultivating once, and simultaneously subsoiling and bedding. Reduced tillage consisted of strip tilling a 40-cm wide band on 91-cm rows using strip tillage implements consisting of two sets of coulters and basket attachments following in-row subsoiling. Depth of subsoiling was 30 to 40 cm with crops planted within 1 wk following reduced tillage or bedding.

Table 7. Influence of rotation and tillage on corn and cotton yield at Lewiston–Woodville, NC.†

	Crop yield									
	1999		2000	2001		2003		2004	2005	
Treatment factor	CR	CT	CT	CT	CR	CT	CR	CT	CR	CT
	kg ha^{-1}									
Crop rotation (1999–2006)										
CT-PN (4 cycles)	–	250	–	980 a‡	–	870 a	–	–	–	910 a
CR-PN (4 cycles)	2280	–	–	–	7270 a	–	8430	–	4350 a	–
CT-CT-CT-PN (2 cycles)	–	280	1280 a	930 a	–	880 a	–	1280 a	–	990 a
CT-CT-CR-PN (2 cycles)	–	280	1340 a	–	7980 a	930 a	–	1340 a	5090 a	–
Tillage system§										
Conventional	2430 a	290 a	1290 a	940 a	7700 a	900 a	8640 a	1290 a	4560 a	920 a
Reduced tillage	2130 a	250 b	1330 a	960 a	7550 a	890 a	8310 a	1330 a	4890 a	980 a

† CR, corn; CT, cotton; PN, peanut.

‡ Means within a treatment factor, crop, and year combination followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$. Data for each treatment factor are pooled over levels of the other treatment factor. Means without a letter for a treatment factor were not analyzed statistically during 1999 for cotton because this was the first year of the rotation. Tillage system can be compared in 1999 for corn and cotton.

§ Conventional tillage consisted of disking twice, field cultivating once, and simultaneously subsoiling and bedding. Reduced tillage consisted of strip tilling a 40-cm wide band on 91-cm rows using strip tillage implements consisting of two sets of coulters and basket attachments following in-row subsoiling. Depth of subsoiling was 30 to 40 cm with crops planted within 1 wk following reduced tillage or bedding.

Table 8. *F* statistic from analyses of variance for peanut plant condition rating at Lewiston–Woodville and Rocky Mount and root knot nematode population in soil at Lewiston–Woodville as influenced by tillage and rotation.

	Lewiston–Woodville			Rocky Mount					
	Plant condition rating		Root knot nematode	Plant condition rating		Nematode species, 2006			
Treatment factor	2002	2006	2006	2002	2006	Lesion	Ring	Spiral	Sting
Rotation	1.5	1.4	101.7**	3.2	0.1	2.0	1.3	3.0	2.1
Tillage	8.1*	0.1	1.5	3.0	0.4	20.7**	1.8	7.3*	14.5**
Rotation × Tillage	0.2	0.9	0.8	1.7	0.7	0.5	0.1	0.5	0.1

* Significant at $P = 0.01$ to 0.05.

** Significant at $P < 0.01$.

was similar in the 4 yr where this comparison was made at Lewiston–Woodville (Table 7).

Plant Condition Rating and Parasitic Nematode Population in Soil

The interaction of crop rotation and tillage system and the main effect of crop rotation were not significant for PCR at either location (Table 8). However, the main effect of tillage system was significant for PCR at Lewiston–Woodville during 2002 but not during 2006 (Table 8). Plants at Lewiston–Woodville expressed symptoms characteristic for TSWV during 2002 and both CBR and TSWV during 2006 (Shew, 2007). At Rocky Mount, plants expressed symptoms associated with TSWV only during both years. When pooled over rotation systems, a higher percentage of the peanut canopy expressed disease symptoms, diagnosed as TSWV, when planted in conventional tillage (14%) compared with reduced tillage (12%) during 2002 (data not presented in tables). At Rocky Mount, PCR was not affected by tillage or rotation during either year (data not presented in tables).

While increasing the number of years between peanut plantings often decreases CBR (Pataky et al., 1983; Phipps and Beute, 1979; Sidebottom and Beute, 1989), our results demonstrated no difference in CBR expression at Lewiston–Woodville during 2002 when comparing rotations with two cycles of corn-peanut or cotton-peanut with one cycle of cotton-cotton-cotton-peanut and cotton-cotton-corn-peanut.

At Lewiston–Woodville during 2006, the main effect of crop rotation was significant for root knot nematode population (Table 8). Main effect of tillage system and the interaction of crop rotation and tillage system were not significant. The length of rotation between peanut crops rather than the crop in that rotation sequence affected root knot nematode population. When pooled over tillage systems, a higher final population of root knot nematode was noted when peanut was planted with only 1 yr of corn or cotton preceded peanut compared with a rotation of cotton-cotton-cotton-peanut or cotton-cotton-corn-peanut (Table 9). Root knot nematode populations in soil were lower when longer rotations were implemented between peanut plantings and are consistent with previous research (Rodriguez-Kabana et al., 1987; Rodriguez-Kabana and Touchton, 1984).

Table 9. Root knot nematode population in soil during 2006 as influenced by rotation at Lewiston–Woodville, NC.†

Crop rotation	Root knot nematode population
	Log no. 500 cm^{-3}
CT-PN	7.5 a‡
CR-PN	7.0 a
CT-CT-CT-PN	0.8 b
CT-CT-CR-PN	1.4 b

† CR, corn; CT, cotton; PN, peanut.

‡ Means followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$. Data are pooled over levels of tillage.

In contrast to results at Lewiston–Woodville, tillage affected populations of lesion, spiral, and stunt nematodes at Rocky Mount (Table 8). However, tillage did not affect population of ring nematode. Nematode populations at this location were not affected by the interaction of rotation and tillage (Table 8). When pooled over rotation, population of lesion nematode was higher in conventional tillage compared with reduced tillage (Table 10). In contrast, populations of spiral and sting nematodes were lower in conventional tillage compared with reduced tillage (Table 10). A lower population of lesion and ring nematodes in conventional tillage compared with reduced tillage is consistent with other research showing lower populations of soybean cyst nematode (*Heterodera glycines Ichinohe*) in conventional tillage compared with reduced tillage (Chen, 2007; Edwards et al., 1988; Temperly and Borges, 2006). McSorley and Gallaher (1994, 1999) reported differences in dagger (*Xiphinema* spp.), lesion, root knot, ring, and stubby-root (*Paratrichodorus minor*) nematodes depending on cropping system but few differences when comparing conventional and reduced tillage cotton. Johnson et al. (2001) reported no effect of tillage on root knot nematode when comparing rotations including cotton and peanut. Lower populations of spiral and sting nematodes in conventional tillage compared with reduced tillage was surprising and requires further investigation to understand implications for management in cropping systems including cotton and peanut.

Many of the experiments documenting lower populations of nematodes in reduced tillage compared with conventional tillage were using standard conventional tillage practices including moldboard plowing with zero tillage. With the exception of nontilled areas between strip-tilled zones, in our research tillage in the planting and pegging zones included considerable tillage including in-row subsoiling.

Cumulative Net Return

Main effects of crop rotation and tillage system were significant for cumulative net return at Lewiston–Woodville (Table 3). In contrast, crop rotation and tillage did not affect cumulative net return at Rocky Mount (Table 4). At both locations the interaction of crop rotation and tillage system was not significant (Tables 3 and 4). The highest CNR was noted

Table 10. Populations of lesion, spiral, and sting nematodes in soil during 2006 as influenced by tillage at Rocky Mount, NC.

	Population of nematodes in soil		
Tillage	Lesion	Spiral	Sting
	Log no. 500 cm^{-3}		
Conventional	3.6 a†	1.1 b	0.5 b
Reduced	1.9 b	3.6 a	3.4 a

† Means followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$. Data are pooled over levels of rotations.

when 3 yr of cotton or cotton-cotton-corn preceded peanut at Lewiston–Woodville (Table 11). Cumulative net return of these rotations exceeded that of 1 yr of corn or cotton separated peanut (Table 11). Cumulative net return of the corn-peanut rotation was higher than CNR of cotton-peanut (Table 11). Cumulative net return was higher in reduced tillage than conventional tillage at Lewiston–Woodville (Table 11). In contrast, no difference in cumulative net return was observed when comparing reduced tillage with conventional tillage at Rocky Mount (Table 4). When pooled over tillage systems, CNR was $257 ha^{-1} in the rotation including cotton during 2000 and 2001 followed by alternating peanut and cotton thereafter compared with $111 ha^{-1} when cotton and peanut were alternated during all years of the experiment (Table 11). When pooled over rotations, CNR was –$136 ha^{-1} in conventional tillage and $503 ha^{-1} in reduced tillage (Table 11).

Differences in CNR at Lewiston–Woodville were not only affected by rotation and tillage but also the year specific crops were planted in the rotation. Considerable difference in environmental conditions occurred over the duration of the experiment. For example, during 1999 three hurricanes or tropical storms damaged crops before harvest and reduced efficiency of harvest at Lewiston–Woodville (Table 2). Lower CNR at Lewiston–Woodville for the shorter rotation with cotton and peanut was a reflection of low cotton yields during 1999 and higher production costs for cotton ($1242 ha^{-1} to $1272 ha^{-1}) compared with corn ($647 ha^{-1} to $687 ha^{-1}) during other years. Additionally, planting more years of corn, cotton, and the combination of these crops between peanut plantings increased peanut yield compared with peanut yield in shorter rotations. In these experiments, where a common cost of production was considered across the duration of the experiment, peanut in shorter rotations with similar costs resulted in lower CNR due to lower yield. Lack of a difference in CNR between rotation systems at Rocky Mount most likely was a reflection of only one difference in the rotations over the duration of the experiment.

Table 11. Cumulative net return as influenced by crop rotation and tillage system in North Carolina at Lewiston–Woodville and Rocky Mount.

Treatment factor†	Cumulative net return	
	Lewiston–Woodville	Rocky Mount
	$ ha^{-1}	
Crop rotation		
CT-PN (4 cycles)	–1290 c‡	111 a
CR-PN (4 cycles)	–101 b	–
CT-CT-CT-PN (2 cycles)	593 a	–
CT-CT-CR-PN (2 cycles)	818 a	–
CT-CT-PN-CT-PN-CT-PN	–	257 a
Tillage system§		
Conventional	–190 b	–136 a
Reduced	198 a	503 a

† CNR, cumulative net return; CR, corn; CT, cotton; PN, peanut.

‡ Means within a treatment factor and location followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$. Data for each treatment factor are pooled over levels of the other treatment factor.

§ Conventional tillage consisted of disking twice, field cultivating once, and simultaneously subsoiling and bedding. Reduced tillage consisted of strip tilling a 40-cm wide band on 91-cm rows using strip tillage implements consisting of two sets of coulters and basket attachments following in-row subsoiling. Depth of subsoiling was 30 to 40 cm with crops planted within 1 wk following reduced tillage or bedding.

Bulk Density in Pegging Zone

Bulk density 10 cm from the planted row at a depth of 0 to 12 cm did not differ when comparing tillage systems and varied from 1.56 to 1.62 g cm^{-3} at Lewiston–Woodville ($P = 0.1083$, $F = 2.2$) and 1.30 to 1.40 g cm^{-3} at Rocky Mount ($P = 0.2374$, $F = 1.5$) (data not shown in tables). These results were not surprising, given that considerable tillage was implemented in the pegging zone in both tillage systems. Results from this research suggest that no difference in bulk density and perhaps pegging of peanut would be expected in the majority of the pegging zone when comparing conventional tillage with reduced tillage that include strip tillage and in-row subsoiling.

In summary, these experiments demonstrate the complexity of cropping systems when biological and economical components are considered. The primary objective of this research was to determine interactions of crop rotations and tillage systems with respect to peanut. Although differences in peanut yield were associated with crop rotation and tillage system, these data suggest that while farmers should expect some differences in peanut yield due to rotation and tillage, response to these management practices most likely will be independent.

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REFERENCES

Anonymous. 2008a. 2008 Peanut information. Publ. AG-331. Available at http://www.peanut.ncsu.edu (verified 11 Aug. 2008). North Carolina Coop. Ext. Serv., Raleigh, NC.

Anonymous. 2008b. The North Carolina corn production guide. Available at http://www.ces.ncsu.edu/plymouth/cropsci/cornguide/index.html (verified 11 Aug. 2008). North Carolina Coop. Ext. Serv., Raleigh, NC.

Anonymous. 2008c. 2008 Cotton information. Publ. AG-417. Available at http://ipm.ncsu.edu/Production_Guides/Cotton/contents.pdf (verified 11 Aug. 2008). North Carolina Coop. Ext. Serv., Raleigh, NC.

Ayers, A.R., H.E. Duncan, K.R. Barker, and K.M. Beute. 1989. Effects of crop rotation and nonfumigant nematicides on peanut and corn yields in fields infested with *Criconemella* species. J. Nematol. 21:268–275.

Balkom, K.S., D.W. Reeves, J.N. Shaw, C.H. Burmester, and L.M. Curtis. 2006. Cotton yield and fiber quality from irrigated tillage systems in the Tennessee valley. Agron. J. 98:596–602.

Boquet, D.J., R.L. Hutchinson, and G.A. Breitenback. 2004. Long-term tillage, cover crops, and nitrogen rates effects on cotton. Agron. J. 96:1436–1442.

Brandenburg, R.L. 2007. Insect management. p. 75–93. *In* 2007 Peanut information. Publ. AG-331. North Carolina Coop. Ext. Serv., Raleigh, NC.

Brown, A.B. 2007. 2007 Economic outlook. p. 3–7. *In* 2007 Cotton information. Publ. AG-417. North Carolina Coop. Ext. Serv., Raleigh, NC.

Bullen, S.G., and D.L. Jordan. 2007. Peanut production budgets. p. 6–18. *In* 2007 Peanut information. Publ. AG-331. North Carolina Coop. Ext. Serv., Raleigh, NC.

Burmester, C.H., D.W. Reeves, and A.C.V. Motta. 2002. Effect of crop rotation/tillage systems on cotton yield in the Tennessee Valley area of Alabama, 1980–2001. p. 354–357. *In* E.van Santen (ed.) Proc. 25th Annual Southern Conservation Tillage Conf. for Sustainable Agriculture, Auburn, AL. 24–26 June 2002. Spec. Rep. 1. Available at http://www.ag.auburn.edu/auxiliary/nsdl/scasc/ (verified 11 Aug. 2008). Alabama Agric. Exp. Stn. and Auburn University, AL.

Byrd, D.W., Jr., K.R. Barker, H. Ferris, C.J. Nusbaum, W.E. Griffin, R.H. Small, and C.A. Stone. 1976. Two semi-automatic elutriators for extracting nematodes and certain fungi from soil. J. Nematol. 8:206–212.

Chen, S. 2007. Tillage and crop sequence effects on *Heterodera glycines* and soybean yields. Agron. J. 99:797–807.

Denton, H.P., and D.D. Tyler. 2002. Making no-till "conventional" in Tennessee. p. 53–58. *In* E. van Santen (ed.) Making Conservation Tillage Conventional: Building a Future on 25 Years of Research. Proc. of 25th Annual Southern Conservation Tillage Conf. for Sustainable Agriculture, Auburn, AL. 24–26 June 2002. Spec. Rep. 1. Available at http://www.ag.auburn.edu/auxiliary/nsdl/scasc/ (verified 11 Aug. 2008). Alabama Agric. Exp. Stn. and Auburn University, AL.

Edwards, J.H., D.L. Thurlow, and J.T. Eason. 1988. Influence of tillage and crop rotation on yields of corn, soybean, and wheat. Agron. J. 80:76–80.

Godsey, C.B., J. Vitale, J.P. Damicone, J.R. Sholar, J. Nickels, and J. Baker. 2007. Rotational effects in Oklahoma peanut production: Prospects for peanut in the post-quota era. Agron. J. 99:1238–1244.

Grandy, A.S., G.P. Robertson, and K.D. Thelen. 2006. Do productivity and environmental trade-offs justify periodically cultivating no-till cropping systems? Agron. J. 98:1377–1383.

Grichar, W.J. 1998. Long-term effects of three tillage systems on peanut grade, yield, and stem rot development. Peanut Sci. 25:59–62.

Hague, S.S., and C. Overstreet. 2002. Crop rotation effects on nematode populations. p. 156–160. *In* E. van Santen (ed.) Proc. 25th Annual Southern Conservation Tillage Conf. for Sustainable Agriculture, Auburn, AL. 24–26 June 2002. Spec. Rep. 1. Available at http://www.ag.auburn.edu/auxiliary/nsdl/scasc/ (verified 11 Aug. 2008). Alabama Agric. Exp. Stn. and Auburn University, AL.

Jenkins, W.R. 1964. A rapid centrifugal-floatation technique for separating nematodes from soil. Plant Dis. Rep. 48:692.

Johnson, W.C., III, T.B. Brenneman, S.H. Baker, A.W. Johnson, D.R. Sumner, and B.G. Mullinix, Jr. 2001. Tillage and pest management considerations in a peanut–cotton rotation in the southeastern Coastal Plain. Agron. J. 93:570–576.

Jordan, D.L., and P.D. Johnson. 2006. Reduced tillage research with peanut in North Carolina (1997–2005). p. 134–140. *In* R.C. Schartz et al. (ed.) Proc. Southern Conservation Tillage Systems Conf., Amarillo, TX. 26–28 June 2006. Rep. 06-1. Available at http://www.ag.auburn.edu/auxiliary/nsdl/scasc/ (verified 11 Aug. 2008). USDA-ARS Conservation and Production Research Laboratory, Bushland, TX.

Jordan, D.L., J.S. Barnes, C.R. Bogle, G.C. Naderman, G.T. Roberson, and P.D. Johnson. 2001. Peanut response to tillage and fertilization. Agron. J. 93:1125–1130.

Jordan, D.L., J.S. Barnes, C.R. Bogle, R.L. Brandenburg, J.E. Bailey, P.D. Johnson, and A.S. Culpepper. 2003. Peanut response to cultivar selection, digging date, and tillage intensity. Agron. J. 95:380–385.

Jordan, D.L., J.E. Bailey, J.S. Barnes, C.R. Bogle, S.G. Bullen, A.B. Brown, K.L. Edmisten, E.J. Dunphy, and P.D. Johnson. 2002. Yield and economic return of ten peanut-based cropping systems. Agron. J. 94:1289–1294.

Katsvairo, T.W., and W.J. Cox. 2000. Tillage × rotation × management interactions in corn. Agron. J. 92:493–500.

Lamb, M.C., J.I. Davidson, and C.L. Butts. 1993. Peanut yield decline in the Southeast and economically reasonable solutions. Peanut Sci. 20:36–40.

Marios, J.J., and D.L. Wright. 2003. Effect of tillage system, phorate, and cultivar on tomato spotted wilt of peanut. Agron. J. 95:386–389.

McSorley, R., and R.N. Gallaher. 1994. Effect of long-term rotation and tillage programs on plant parasitic nematodes. p. 23–28. *In* P.J. Bauer and W.J. Busscher (ed.) Proc. 1994 Southern Conservation Tillage Conf. for Sustainable Agriculture, Columbia, SC. 7–9 June 1994. Available at http://www.ag.auburn.edu/auxiliary/nsdl/scasc/ (verified 11 Aug. 2008). USDA-ARS Coastal Plains Soil, Water, and Plant Research, Florence, SC.

McSorley, R., and R.N. Gallaher. 1999. Nematode populations on Roundup-Ready cotton in Florida. p. 114–118. *In* J.E. Hook (ed.) Proc. of the 22nd Annual Southern Conservation Tillage Conf. for Sustainable Agriculture, Tifton, GA. 6–8 July 1999. http://www.ag.auburn.edu/auxiliary/nsdl/scasc/ (verified 11 Aug. 2008). Univ. of Georgia, Athens.

Monfert, W.S., A.K. Culbreath, K.L. Stevenson, T.B. Brenneman, D.W. Gorbet, and S.C. Phatak. 2004. Effects of reduced tillage, resistant cultivars, and reduced fungicide inputs on progress of early leaf spot of peanut (*Arachis hypogaea*). Plant Dis. 88:858–864.

Naderman, G., B. Brock, G.B. Reddy, and C.W. Raczkowski. 2004. Continuous conservation tillage: Effects on soil density, soil C and N in the prime rooting zone. p. 15–25. *In* D. Jordan and D. Caldwell (ed.) Proc. 26th Conservation Tillage Conf. for Sustainable Agric. North Carolina Agricultural Research Service Tech. Bull. TB-321. Available at http://www.ag.auburn.edu/auxiliary/nsdl/scasc/ (verified 11 Aug. 2008). North Carolina Agric. Res. Serv., Raleigh, NC.

Overstreet, L.R., G. Hoyt, W. Shi, and R. Wagger. 2004. Comparing biological and structural features of soil under conventional and conservation tillage. p. 126–134. *In* D. Jordan and D. Caldwell (ed.) Proc. 26th Conservation Tillage Conf. for Sustainable Agric. North Carolina Agricultural Research Service Tech. Bull. TB-321. Available at http://www.ag.auburn.edu/auxiliary/nsdl/scasc/ (verified 11 Aug. 2008). North Carolina Agric. Res. Serv., Raleigh, NC.

Pataky, J.K., M.K. Beute, J.C. Wynne, and G.A. Carlson. 1983. A critical-point yield loss model for *Cylindrocladium* black rot of peanut. Phytopathology 73:1559–1563.

Phipps, P.M., and M.K. Beute. 1979. Population dynamics of *Cylindrocladium crotalaria* microsclerotia in naturally infested soil. Phytopathology 69:240–243.

Porter, P.M., J.G. Lauer, W.E. Lueschen, J.H. Ford, T.R. Hoverstad, E.S. Oplinger, and R.K. Crookston. 1997. Environment affects the corn and soybean rotation effect. Agron. J. 89:442–448.

Raimbault, B.A., and T.J. Vyn. 1991. Crop rotation and tillage effects on corn growth and soil structural stability. Agron. J. 83:979–985.

Reddy, K.N., M.A. Locke, C.H. Koger, R.M. Zablotowicz, and L.J. Kurtz. 2006. Cotton and corn rotation under reduced tillage management: Impacts on soil properties, weed control, yield, and net return. Weed Sci. 54:768–774.

Rodriguez-Kabana, R., H. Ivey, and P.A. Backman. 1987. Peanut-cotton rotations for management of *Meloidogyne arenaria*. J. Nematol. 19:484–487.

Rodriguez-Kabana, R., and J.T. Touchton. 1984. Corn and sorghum rotations for management of *Meloidogyne arenaria* in peanut. Nematropica 14:26–36.

Rowland, D.L., W.H. Faircloth, and C.L. Butts. 2007. Effects of irrigation method and tillage regime on peanut (*Arachis hypogaea* L.) reproductive processes. Peanut Sci. 34:85–95.

Shew, B.B. 2007. Peanut disease management. p. 94–118. *In* 2007 Peanut information. Publ. AG-331.North Carolina Coop. Ext. Ser., Raleigh.

Sholar, J.R., R.W. Mozingo, and J.P. Beasley, Jr. 1995. Peanut cultural practices. p. 354- 382. *In* H.E. Pattee and T.H. Stalker (ed.) Advances in peanut science. Am. Peanut Res. and Educ. Soc., Stillwater, OK.

Sidebottom, J.R., and M.K. Beute. 1989. Inducing soil suppression to *Cylindrocladium* black rot of peanut through crop rotations and soybean. Plant Dis. 73:679–685.

Temperly, R.J., and R. Borges. 2006. Tillage and crop rotation impact on soybean grain yield and composition. Agron. J. 98:999–1004.

Vetsh, J.A., and G.W. Randall. 2002. Crop production as affected by tillage system and starter fertilizer. Agron. J. 94:532–540.

Vetsh, J.A., G.W. Randall, and J.A. Lamb. 2007. Corn and soybean production as affected by tillage systems. Agron. J. 99:952–959.

Wright, S.F., and D.M. Porter. 1995. Conservation tillage and cultivar influence on peanut production. Peanut Sci. 22:120–124.