Response of nematodes and Palmer amaranth to tillage and rye green manure

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Winter cover crops can reduce soil erosion and loss of nutrients from leaching and runoff as well as increase soil organic matter and water infiltration. Rye is used as a winter cover crop in many agronomic production systems in the eastern and southeastern United States because it establishes reliably, grows rapidly, and produces large amounts of biomass. It is typically killed with a nonselective herbicide several weeks before planting the next crop in the spring. In conventional tillage, the residue is chopped with a flail mower and incorporated while in conservation tillage, the rye is either chopped or rolled flat, and the residue is left as a mulch on the soil surface.

Rye may also benefit the succeeding crop by suppressing pests. Many cereals, including rye, produce secondary metabolites called benzoxazinoid hydroxamic acids (syn. benzoxazinones), which are toxic to a broad spectrum of organisms including weeds, insects, and plant pathogens. These compounds are present in the plant as glucosides that are hydrolyzed to the more toxic aglucones following tissue injury. The primary benzoxazinoids in rye are DIBOA in aerial tissue and a mixture of BOA, DIBOA, DIMBOA, and its breakdown product, MBOA, in root tissue; however, only DIBOA has been found in the root exudates. Several benzoxazinoid compounds in addition to DIBOA have now emerged as possible contributors to the bioactivity from rye, especially when the rye materials decompose in the soil. Allelopathic suppression of weeds by rye is believed to occur both during the vegetative stage, from benzoxazinoids in the root exudates, and after crop destruction, from leaching of benzoxazinoids in the residue.

Palmer amaranth has become the most troublesome weed of cotton production in the southern United States due to the development and increase in frequency of plants resistant to glyphosate and other commonly used herbicides. In the absence of glyphosate, control of Palmer amaranth in reduced-tillage systems requires activation of pre-emergence herbicides by soil moisture. With approximately 50% of the cotton and peanut area in Georgia without supplemental irrigation, many growers cannot consistently manage Palmer amaranth. Weed control from cover crop residues may help. Previous research shows that the effectiveness of mulch residues as a component of a weed management system depends on the weed's seed size. Since Palmer amaranth has a small seed compared with other common weeds in the southern United States, rye residues could suppress emergence of this troublesome weed.

The southern root-knot nematode (SRKN) and the peanut root-knot nematode (PRKN) are major pests of cotton and peanut, respectively. Wrens Abruzzi, the predominant rye cultivar planted in the southern United States, is a relatively poor host for these two nematode species. Studies have demonstrated that populations of SRKN and PRKN do not appreciably increase or decrease following a winter cover crop of rye. The lack of a detectable population increase is likely due to a combination of low soil temperatures and a low reproductive potential. The traditional method of managing rye (i.e., killing before incorporation or mulching) may not suppress populations of root-knot nematodes compared with winter fallow; however, in a greenhouse study, incorporation of freshly cut rye into soil reduced galling of cotton roots by SRKN. Greater concentrations of benzoxazinoids may be released by incorporating rye into soil at an earlier stage of growth because the concentration of DIBOA and BOA in aerial tissue declines as rye matures. Moreover, incorporating organic matter, rather than leaving it on the soil surface, results in more

Abbreviations: PRKN, peanut root-knot nematode; SRKN, southern root-knot nematode.

Root-knot nematode on soybean. Photo by Edward Sikora, Auburn University, Bugwood.org.

rapid decomposition, which may lead to faster release of benzoxazinoids.

In the May–June 2011 issue of *Agronomy Journal*, researchers set out to (i) determine whether incorporating rye into the soil while it's still green (i.e., green manuring) results in greater suppression of root-knot nematodes and Palmer amaranth than killing rye before mulching and (ii) to compare different rye cultivars for their effect on population densities of the two pests. The cultivars tested (Elbon, Oklon, Wheeler, and Wrens Abruzzi) contained similar concentrations of total benzoxazinoids when grown under greenhouse conditions but differed in their host status for root-knot nematodes. Reproduction of SRKN was greater on Wheeler than on Wrens Abruzzi and Oklon.

Two similar experiments were conducted concurrently, one with cotton and the other with peanut, at the University of Georgia Gibbs Farm in Tifton, GA. The three tillage treatments were conventional tillage, green manure, and strip tillage. The five cover crop treatments were a weedy fallow and the four rye cultivars listed above. Applications of insecticides and herbicides for both cotton and peanut followed University of Georgia Extension Service recommendations and were the same for all plots. Irrigation was applied as needed through overhead sprinklers.

Results

There was no difference in the concentration of benzoxazinoids in the rye between the cotton and peanut experiments; therefore, data from the two experiments were combined for analysis (Table 1). There was a difference between years ($P < 0.01$), with higher concentrations of all of benzoxazinoid components (averaged across rye cultivars) in 2007 compared with 2008. In 2007, Wrens Abruzzi always had the lowest concentrations and Wheeler the highest concentrations of benzoxazinoids, regardless of type, and the difference in benzoxazinoid concentrations between these two cultivars was significant ($P < 0.001$). In 2008, Wheeler had higher concentrations of most of the benzoxazinoid components than the other cultivars except for DIBOA- and HBOA-glucose.

Only the above-ground portion of the rye cultivars was chemically characterized, and the nonmethoxy benzoxazinoids (DIBOA-glucose, HBOA-glucose, DIBOA, BOA, and HBOA) were the dominant component of the benzoxazinoids in these cultivars. The nonmethoxy benzoxazinoids included 95–99% and methoxy benzoxazinoids 1–5% of the total benzoxazinoids across cultivars and years. In both 2007 and 2008, DIBOA was the major benzoxazinoid in the rye cultivars at 54–72% of the total. Differences among the cultivars in benzoxazinoid compounds and concentration all but disappeared when total benzoxazinoid concentration was calculated based on dry

Table 1. Concentration of benzoxazinoids in the above-ground rye tissue before incorporation of the cover crop.

Rye cultivar †	DIBOA-glucose	HBOA-glucose	DIBOA	BOA	HBOA	Methoxy ‡	Total
	ppm						
				2007			
Wrens Abruzzi	1.1	0.5 b §	13.0 b	4.4 b	1.9 b	0.6	21.5 b
Elbon	1.3	0.8 ab	26.7 ab	7.0 ab	4.0 ab	1.1	40.4 ab
Oklon	1.2	1.0 ab	42.4 ab	9.3 a	4.6 ab	0.6	59.3 ab
Wheeler	0.7	1.1 a	76.2 a	16.1 a	10.2a	0.9	105.5 a
				2008			
Wrens Abruzzi	0.4	0.4	5.4 b	1.2 b	0.8 b	0.4 b	8.6 b
Elbon	0.4	0.7	5.4 b	2.0 b	1.0 b	0.5 b	10.0 b
Oklon	0.4	0.7	8.1 b	3.1 b	1.7 b	0.5 b	14.3 b
Wheeler	0.4	0.4	34.0 a	12.9 a	8.5 a	1.0 a	57.4 a

† Rye was planted mid-November and incorporated as a green manure the first week in April.

‡ Methoxy benzoxazinoids are DIMBOA-glucose, DIMBOA, MBOA, and HMBOA.

§ Values within a column and year followed by the same letter (or no letters) are not different ($P < 0.05$) according to Fisher's Protected LSD.

matter biomass. The only exception was in the cotton experiment in 2008, where the rate of total benzoxazinoids applied to the soil was significantly higher in Wheeler compared with the other rye cultivars.

The effect of rye cover crop on Palmer amaranth emergence was not consistent among tillage treatments (cover crop × tillage interaction, $P = 0.03$). Where there was substantial soil disturbance (e.g., conventional tillage and green manure), Palmer amaranth densities were low and not influenced by cover crop (Table 2). In the strip tillage, however, all of the rye cultivars, except Wheeler, reduced establishment of the weed compared with winter fallow.

Table 2. Effect of tillage and rye cover crop on the density of Palmer amaranth in cotton.

Cover crop/ rye cultivar	Conventional tillage	Green manure	Strip tillage
	Palmer amaranth plants/yd^2		
Fallow	2.8 c†	2.3 c	15.1 a
Wrens Abruzzi	3.0 c	2.2 c	4.4 bc
Wheeler	3.4 c	2.8 c	13.3 ab
Elbon	2.8 c	3.6 c	4.1 bc
Oklon	3.4 c	5.0 bc	4.0 c

† Values within the table followed by the same letter are not different ($P < 0.05$) according to Fisher's Protected LSD.

Root galling on cotton caused by SRKN was influenced by tillage ($P = 0.0002$) but not by rye cover crop. Gall indices on cotton were greater in conventional tillage plots than in either strip tillage or green manure plots, and this trend was consistent across cover crop treatments and years. Densities of SRKN juveniles in the soil showed a similar trend on some sampling occasions. Soil densities of the nematode were greater in conventional and strip tillage plots than in the green manure plots early in the season and greater in conventional tillage plots than the green manure plots at harvest in 2008 (Table 3). On other sampling occasions, there were no differences among the tillage treatments. Cover crop influenced soil densities of SRKN on only one occasion: late-season densities of the nematode were lower in fallow than in most of the rye cultivars except Oklon, which had similar densities to fallow. Cotton yield was lower in 2007 than in 2008 but was not influenced by either tillage or cover crop.

Root-gall indices on peanut caused by PRKN were greater ($P < 0.0001$) in 2007 than in 2008; averaged across treatments, they were 7.6 and 6.5, respectively. Galling of peanut roots was influenced by tillage ($P < 0.0001$) but not by rye cover crop. Gall indices were greater in the strip tillage plots than in the conventional tillage or green manure plots. Soil densities of PRKN juveniles tended to be greater in the strip tillage plots than in the other plots but were only significantly different at mid-season of 2008 (Table 4). Rye cover crop did not influence soil densities of the nematode on any sampling occasion. In 2007, peanut yields were low and not influenced by tillage or rye cover crop. In 2008, peanut yields were 1.9-fold greater ($P < 0.0001$) than in 2007 and were influenced by tillage but not by cover crop. Peanut yield in 2008 was lower in strip tillage than in conventional tillage or green manure plots.

Table 3. Influence of tillage and rye cover crop on population density of southern root-knot nematode juveniles in cotton.

				Harvest	
Tillage/rye cover crop	Early season †	Mid-season	Late season	2007	2008
	no. of second-stage juveniles per 150 cm^3				
Tillage					
Conventional	102 a ‡	346	1,259	728	1,225 a
Strip	89 a	313	1,269	757	1,040 ab
Green manure	50 b	268	1,064	918	930 b
	$P = 0.004$	$P = 0.38$	$P = 0.07$	$P = 0.09$	$P = 0.03$
Cover crop/rye cultivar					
Fallow	89	304	930 b	818	
Wheeler	86	292	1,237 a	1,011	
Oklon	84	346	1,180 ab	918	
Wrens Abruzzi	73	293	1,279 a	916	
Elbon	72	310	1,360 a	1,000	
	$P = 0.88$	$P = 0.95$	$P = 0.01$	$P = 0.29$	

† Unless otherwise indicated, values are the means from 2007 and 2008. There was an interaction between tillage and year ($P = 0.007$) for the harvest sampling time; therefore, data are presented for each year.

‡ Values within a column followed by the same letter (or no letters) are not different ($P < 0.05$) according to Fisher's Protected LSD.

Discussion

The rye cultivars varied in the amount of above-ground biomass produced at the field sites in Tifton, GA. As rye matures, there is a decline in tissue concentrations of benzoxazinoids. In a North Carolina study, the rate of decline was less in Wheeler than in Wrens Abruzzi, possibly due to the slower development of Wheeler. The researchers also found a greater concentration of benzoxazinoids, including DIBOA, in Wheeler than in Wrens Abruzzi; Oklon and Elbon generally had intermediate concentrations. However, when the rate of benzoxazinoids was determined (biomass × tissue concentration), there were few consistent differences among the cultivars.

Incorporating rye as a green manure in early April did not enhance suppression of Palmer amaranth compared with conventional tillage or winter fallow. Rye is more effective in reducing weed seedling emergence when left on the soil surface as mulch than when incorporated into soil. The physical effects of the rye residue, however, cannot fully explain the emergence pattern of Palmer amaranth among the rye cultivars. For example, Wrens Abruzzi produced more above-ground biomass than Oklon or Elbon, which, if the mulches only represented a physical barrier, should have led to greater weed suppression. However, these three cultivars had equivalent weed control (Table 2). Allelopathic residues from rye have been implicated in reducing weed growth. There was no correlation between growth inhibition and benzoxazinoid content among the eight cultivars of rye evaluated.

In the absence of a cover crop, Palmer amaranth population density was greater in strip tillage than in the green manure and conventional tillage treatments. Palmer amaranth seeds in this study were spread on the soil surface after rye had emerged. In spite of the lack of a naturalized Palmer amaranth soil seedbank, the results of this study were consistent with previous research.

Compared with winter fallow, none of the rye cultivars increased or decreased galling of either cotton or peanut roots by root-knot nematodes. Incorporating the rye into the soil as a green manure did not suppress root-knot nematode populations.

Tillage had a consistent effect on root-knot nematodes within each experiment, but the effect of tillage differed between the cotton and peanut experiments. In the peanut

Table 4. Influence of tillage and rye cover crop on population density of peanut root-knot nematode juveniles in peanut.

Tillage/rye cover crop	Early season †	Mid-season 2007	Mid-season 2008	Harvest
	no. of second-stage juveniles per 150 cm^3			
Tillage				
Conventional	153	104	138 b ‡	790
Strip	115	138	302 a	940
Green manure	121	93	120 b	842
	$P = 0.15$	$P = 0.13$	$P < 0.0001$	$P = 0.38$
Cover crop/rye cultivar				
Fallow	130	137		759
Wheeler	131	131		766
Oklon	139	139		976
Wrens Abruzzi	106	165		841
Elbon	142	174		944
	$P = 0.72$	$P = 0.32$		$P = 0.41$

† Unless otherwise indicated, values are the means from 2007 and 2008. There was an interaction between tillage and year ($P = 0.0005$) for the mid-season sampling time; therefore, data are presented for each year.

‡ Values within a column followed by the same letter (or no letters) are not different ($P < 0.05$) according to Fisher's Protected LSD.

experiment, the substantial tillage used in the conventional and green manure treatments suppressed root galling and soil densities of PRKN compared with the strip tillage treatment. Tillage also disperses the nematode population, and many nematodes may be deposited far from the future root zone.

The response of SRKN to tillage in the cotton experiment is difficult to explain. In that experiment, root galling and soil densities of the nematode were lower in strip tillage than in conventional tillage, the opposite of what we observed in the peanut experiment. However, in another tillage experiment involving cotton, the researchers found less galling from SRKN in strip tillage than in conventional tillage plots. The primary difference between the cotton and peanut experiment was the host plant for the root-knot nematodes and the type of conventional tillage used, both of which may have played a role in the differential response of the two root-knot species to tillage.

The type of tillage equipment used may also differentially affect nematode populations. The only difference in tillage between the conventional tillage and green manure treatments was the additional rototilling. Therefore, the lower populations of SRKN in the green manure plots (including the fallow) compared with the conventional plots appear to be due to rototilling. Suppression of SRKN second-stage juveniles was observed shortly after rototilling, indicating that inversion of the soil exposed the nematodes to greater mortality.

Substantial soil disturbance as a result of conventional tillage and green manuring decreased Palmer amaranth emergence but had differential effects on root-knot nematode populations in the cotton and peanut experiments. In the cotton experiment, root galling was greatest in conventional tillage; but in the peanut experiment, galling was greatest in strip tillage. Increased nematode damage in the strip-tilled peanut likely contributed to the lower yield compared with peanut in plots with substantial tillage. Differences in root galling of cotton among the tillage treatments may have been too small to affect yield.

Three of the four rye cultivars (Elbon, Oklon, and Wrens Abruzzi) reduced emergence of Palmer amaranth compared with fallow only under strip tillage. The primary mechanism appeared to be the physical barrier created by the rye mulch. Compared with the other cultivars, Wheeler produced the lowest above-ground biomass, but often had the highest concentration of total benzoxazinoids, including DIBOA. In cotton in 2008, the total amount of benzoxazinoids in the rye biomass was greater for Wheeler than for the other cultivars; nevertheless, Wheeler, unlike the other cultivars, did not reduce emergence of Palmer amaranth relative to the fallow. Allelopathy may have contributed to weed suppression in Elbon and Oklon because the biomass of these cultivars was less than that of Wrens Abruzzi, yet these three cultivars provided the same level of Palmer amaranth suppression. None of the rye cultivars suppressed populations of root-knot nematodes in cotton or peanut.

Adapted from the Agronomy Journal *article, "Response of Root-Knot Nematodes and Palmer Amaranth to Tillage and Rye Green Manure," by P. Timper, R.F. Davis, T.M. Webster, T.B. Brenneman, S.L.F. Meyer, I.A. Zasada, G. Cai, and C.P. Rice. Agron. J. 103:813–821.*