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PLANT PATHOLOGY AND NEMATOLOGY

Rye Residue Levels Affect Suppression of the Southern Root-Knot Nematode in Cotton

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ABSTRACT

In the southeastern U.S., rye (*Secale cereale*) is frequently planted as a winter cover crop in conservation tillage cotton. Although rye produces toxic benzoxazinoid compounds that might play a role in nematode suppression, it is also a host for the southern root-knot nematode *Meloidogyne incognita*, a major pathogen of cotton in the U.S. The objective of this study was to determine whether a high-residue rye cover crop would reduce populations of *M. incognita* compared to fallow soil and the standard rye cover crop. The study was conducted in a field infested with *M. incognita*. The experiment was repeated four times from 2012 to 2015 and was a randomized complete block design with three cover crop treatments (weedy fallow, standard rye, and high-residue rye), each replicated eight times. At mid-season of the cotton crop, nematode numbers in soil were greatest in the standard rye, lowest in the high-residue rye, and intermediate in the fallow treatment. After cotton harvest, standard rye had greater numbers of nematodes in the soil than the other cover-crop treatments. Root galling caused by *M. incognita* showed a similar trend as the mid-season numbers with the greatest galling in the standard rye and the lowest galling in the high-residue rye treatment. Planting high-residue rye solely for suppression of *M. incognita* is probably not economical. However, if farmers plant high-residue rye to improve soil structure, moisture retention, and weed control, then they could benefit also from lower populations of *M. incognita*.

In the southeastern U.S., rye (*Secale cereale* L.) is frequently planted as a winter cover crop in conservation tillage cotton (*Gossypium hirsutum* L.) (Tyler et al., 2000). The rye typically is terminated with glyphosate 2 to 4 weeks prior to planting the summer crop and the residue left on the soil surface. Although planting winter cover crops increases production costs, they are beneficial to succeeding crops because they reduce soil erosion, improve water infiltration into soil, limit runoff and leaching of nutrients, increase soil organic matter, and suppress weeds (Dabney et al., 2001; Lu et al., 2000; Reeves, 1994). In spring, the residue from cover crops reduces weed emergence primarily by physical interference and light deprivation (Teasdale and Mohler, 2000). Rye also produces toxic benzoxazinoid (BX) compounds that can play a role in weed suppression, but this allelopathic effect can be masked by the physical effects of the residue on weed emergence (Rice et al., 2012; Yenish et al., 1995).

Rye is a host for the southern root-knot nematode *Meloidogyne incognita* (Kofoid & White) Chitwood, a major pathogen of cotton in the U.S. Under optimal temperatures in the greenhouse, populations of this nematode can increase by 2- to 10-fold after approximately two nematode generations (Ibrahim, 1993; Zasada et al., 2007). Under field conditions, however, low soil temperatures over the winter slow infection and development of *M. incognita* resulting in no detectable increase in populations of this nematode on rye, despite being a host (Johnson and Motsinger, 1990; McSorley and Gallaher, 1994; Minton, 1992; Minton and Bondari, 1994; Minton and Parker, 1987; Timper et al., 2006). Bioassays suggest that BX compounds in rye are toxic to second-stage juveniles (J2) of *M. incognita* and to a lesser extent, eggs of the nematode (Zasada et al., 2005). However, an experiment in soil indicated that high concentrations of BX compounds are required to reduce *M. incognita* populations (Meyer et al., 2009). These compounds are released in root exudates and from the rye residue after crop termination (Perez and Ormeno-Nunez, 1991; Yenish et al., 1995). In a previous field study, rye residue left on the soil surface as a mulch or incorporated into soil as a green manure did not reduce populations of either *M. incognita* in cotton or *Meloidogyne arenaria* (Neal) Chitwood in peanut (*Arachis hypogaea* L.) (Timper et al., 2011). This lack of nematode suppression by the rye cover crop was likely due to low concentrations of BX released from the residue into the soil. Concentra-

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tions of BX in soil are related to the amount of BX in the tissue as well as the biomass of rye residue.

High-residue cover crops are intensively managed to maximize biomass. Because greater levels of biomass on the soil surface more effectively block light and physically restrict growth of weed seedlings than lower levels of biomass, high-residue cover crops such as rye are recommended as part of an integrated management program for glyphosate-resistant Palmer amaranth (*Amaranthus palmeri* S. Wats.) in the southeastern U.S. (Price et al., 2011). Moreover, if deep tillage is used as a strategy to bury Palmer amaranth seed, then high-residue cover crops can mitigate the negative effects of tillage on soil structure and biological activity. An additional benefit of a high-residue rye crop can be suppression of plant-parasitic nematodes via the release of toxic BX compounds. The objective of this study was to determine whether a high-residue rye cover crop would reduce populations of *M. incognita* compared to fallow soil and the standard rye cover crop.

MATERIALS AND METHODS

Experimental Design and Rye Management. The experiment was conducted at the University of Georgia Gibbs Farm in Tifton, GA. The field site contained a Tifton loamy sand (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults; 85% sand, 11% silt, 4% clay, < 1% organic matter) and was naturally infested with *M. incognita* race 3. Corn (*Zea mays* L.) had been grown the summer before the experiment was initiated. The experiment was a randomized complete-block design with three cover crop treatments (weedy fallow, standard rye, and high-residue rye), each replicated eight times. Plots were 7.62 m long x 5.49 m wide (equivalent of six cotton rows). The experiment was conducted four times in the same location from 2012 to 2015. To determine the cumulative effects of a rye cover crop, the treatments were not re-randomized each year.

Rye, cv. Wrens Abruzzi, was planted from 5 December to 20 January (Table 1) with a no-till grain drill (8-cm spacing) at 84 kg ha^{-1} for the standard rye and 101 kg ha^{-1} for the high-residue rye. In the high-residue rye plots, 33.6 kg ha^{-1} of nitrogen (ammonium nitrate) was applied on 19 January 2012, 1 February 2013, 19 February 2014, and 4 March 2015 to enhance biomass production. Rye biomass was determined in 2013, 2014, and 2015 by cutting a 91.4-cm strip from the center of the rye plots using a Carter forage harvester between 23 April and 13 May (Table 1). The biomass of the mowed material from each plot was weighed and a 10% subsample was retained for dry weight determination. The remaining residue was scattered evenly over the cut area. Plant biomass in the weedy fallow treatment was not determined. Glyphosate (1.35 kg a.i. ha^{-1}) was applied on 28 March 2012, 6 May 2013 and 2014, and 14 May 2015 to kill weeds and the rye (burndown). The rye was mowed prior to planting cotton.

Planting and Harvest of Cotton. All plots were strip tilled and planted with cotton at a rate of 10 seed m^{-1} on 12 May 2012, 3 June 2013 and 2014, and 27 May 2015. The cotton cultivar differed among years, with 'DP 1048' planted in 2012 and 2013 and 'Phytogen 499 WRF' planted in 2014 and 2015. The cotton was side dressed with 100.9 kg ha^{-1} liquid nitrogen between 38 and 49 days after planting. The crop was managed uniformly across plots according to University of Georgia Extension Service recommendations and overhead irrigation was applied as needed. Cotton was harvested on 25 October 2012, 21 November 2013, 9 December 2014, and 16 November 2015 and seed weight determined for each plot. Lint yield was estimated as 38% of the seed cotton weight.

Table 1. Biomass of rye residue in standard and high-residue treatments among years

Year	Planting	Harvest[Z]	Degree days	Standard rye	High-residue rye	Average
				kg ha^{-1} (dry weight)		
2012	5 Dec 2011	-[Y]		-	-	
2013	20 Dec 2012	23 Apr 2013	1069	2500	3615	3058
2014	6 Jan 2014	28 Apr 2014	938	962	3090	2026
2015	20 Jan 2015	13 May 2015	1300	784	1060	922
Average			1102	1415 a	2588 b	

[Z]Harvested for biomass weight. The rye was desiccated with glyphosate within 2 wk of biomass collection.

[Y]Biomass weight was not collected in 2012.

Nematode Data Collection. Soil samples to determine numbers of *M. incognita* J2 were collected from each plot after cotton was planted (9-29 d after planting), mid-season (mid-August to mid-September), and after cotton harvest (8-25 d after harvest). The soil samples consisted of a composite of 8 to 10 cores per plot (2.5-cm diameter and 20-cm deep) collected from the root zone. Nematodes were extracted from 150 cm^3 soil by centrifugal flotation (Jenkins, 1964). In 2014 and 2015, a survival bioassay was conducted using the soil collected after planting to determine whether survival of plant-parasitic nematodes was lower in high-residue rye plots than in the fallow or standard rye plots. The bioassay consisted of a 100-cm^3 subsample of soil per plot that was added to a 120-cm^3 capacity jar. The jars were gently tapped to settle the soil, inoculated with 2000 vermiform stages of the reniform nematode (*Rotylenchulus reniformis* Linford & Oliveira), and closed with screw-top lids. Reniform nematode was used for the bioassay because it is easily distinguished from the native nematodes in the soil. Nematodes were extracted by centrifugal flotation 5 d later and the number of live reniform nematodes was counted. Root galling in cotton was evaluated on 5 December 2012, 18 December 2013, 7 January 2014, and 9 December 2015. Six root systems from each plot were rated for galling based on the percentage of the root system with galls (0 to 10 scale) where 0 = no galling, 1 = 1 to 10% of the root system galled, 2 = 11 to 20%, etc., with 10 = 91 to 100%.

Statistical analyses. Mixed model analysis was used to determine whether the rye treatment influenced the number of *M. incognita* J2, survival of the reniform nematode, root galling, or cotton yield. In the analysis, rye treatment was a fixed effect and year, replication, and replication (year) were random effects (JMP Pro 13). Pairwise differences among cover crop treatments was determined with Student's *t* method ($\alpha = 0.05$)

RESULTS AND DISCUSSION

Averaged across treatments, growth of the rye varied among years with the greatest average biomass in 2013, the lowest biomass in 2015, and intermediate biomass in 2014. Averaged across years, the rye biomass was greater in the high-residue treatment than in the standard rye treatment ($p < 0.0001$; Table 1). Although the residue in the weedy fallow plots was not determined, the weed densities were considerably lower than the plant density in the standard rye treatment. Rye biomass tends to decline as planting dates extend into January, with the ideal planting window between mid-October to mid-November (Price et al., 2016; Webster et al., 2016). In this study, planting dates for rye were later than recommended, which likely led to low biomass yields. The late planting of rye was caused by a delay in harvesting cotton due to weather and equipment availability, issues that also can postpone rye planting in farmers' fields. In all years of the study, the lower biomass in the high-residue treatment was lower than what is recommended for suppression of Palmer amaranth (> 4,500 kg ha^{-1}; Price et al., 2016). Cotton lint yield was similar among cover-crop treatments, averaging 1535 kg ha^{-1} across years and treatments.

After planting cotton, numbers of *M. incognita* J2 in soil were low and not different among the cover-crop treatments (Fig. 1A). Treatment differences often are difficult to detect early in the growing season because nematode populations are naturally low due to winter mortality. By mid-season, numbers of J2 were greatest ($p = 0.05$) in the standard rye, lowest in the high-residue rye, and intermediate in the fallow treatment. After cotton harvest, the standard rye still had greater ($p = 0.04$) numbers of J2 in the soil than the other cover-crop treatments. Root galling caused by *M. incognita* showed a trend similar to the mid-season J2 numbers with the greatest galling in the standard rye and the lowest galling in the high-residue rye treatment (Fig. 1B). The tendency for numerically greater populations of *M. incognita* in the standard rye compared to the fallow could be the result of nematode reproduction on the rye. The greatest difference among treatments, however, was between the standard rye and the high-residue rye. Although *M. incognita* would have reproduced on both rye treatments, the larger amount of rye biomass in the high-residue treatment could have suppressed nematode numbers.

Figure 1A. Influence of winter fallow, standard rye (*Secale cereale*) and high-residue rye on (A) population densities of *Meloidogyne incognita* second-stage juveniles (J2). At plant, mid-season, and post-harvest indicate sampling times in the cotton crop.

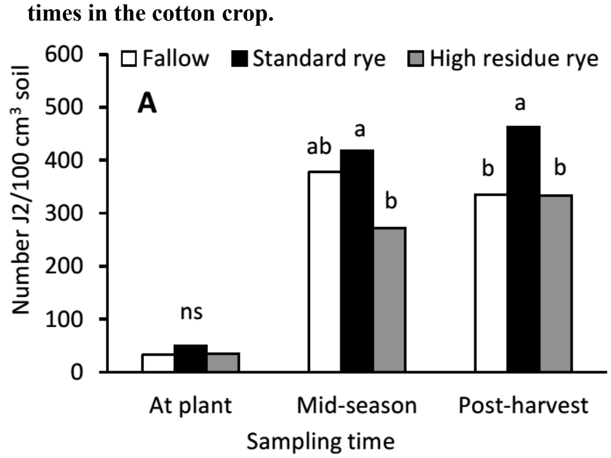
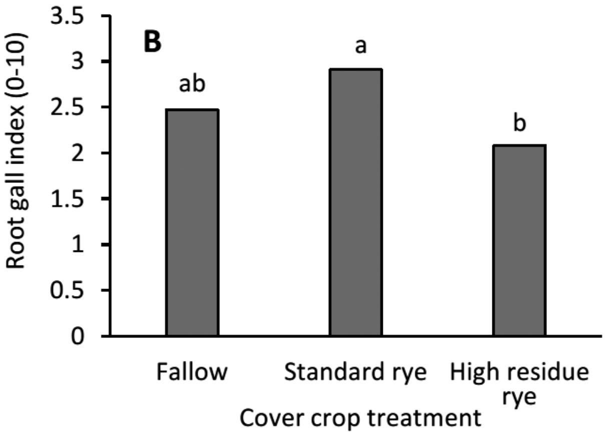


Figure 1B. Influence of winter fallow, standard rye (*Secale cereale*) and high-residue rye on (B) root-gall indices in cotton. At plant, mid-season, and post-harvest indicate sampling times in the cotton crop.



The mechanism by which the high-residue rye suppressed populations of *M. incognita* is not clear. Greater concentrations of BX compounds released from high-residue compared to standard rye could have killed eggs and J2 of the nematode in soil. In 2014 and 2015, we conducted a bioassay 2 to 3 wk after planting cotton to determine survival of the reniform nematode in soil. However, no difference in survival of the nematodes was observed among cover-crop treatments suggesting toxic compounds were not present at lethal levels at this time. Field and laboratory studies indicate that BX compounds disappear rapidly from soil (Meyer et al., 2009; Rice et al., 2012). Rice et al. (2012) demonstrated that after mulching rye residue on the soil surface, concentrations of BX compounds persisted in the soil for several days at low levels relative to leaf tissue concentrations before declining rapidly over a 2-wk period. If BX compounds were responsible for reducing populations of *M. incognita*, their activity would have occurred within 2 wk of rye termination.

Rye residue on the soil surface can reduce soil temperatures by 2 to 5 °C compared to bare soil depending on environmental conditions and the level of residue decomposition (Teasdale and Mohler, 1993). Lower soil temperatures could have delayed egg hatch and development of *M. incognita* in the high-residue rye compared to the fallow, thus leading to differences in population development. However, reduced soil temperatures cannot explain the greater population densities of *M. incognita* and greater galling in the standard rye treatment compared to the high-residue rye and fallow treatments because the intermediate residue levels in the standard rye should have also resulted in lower soil temperatures compared to fallow.

The results of this study demonstrate a small, but statistically significant, reduction in populations of *M. incognita* in cotton following a winter cover of high-residue compared to standard rye. This reduction in the nematode population resulted in a 10% decline in the level of root galling in cotton and no effect on cotton yield. Although there was almost a 2-fold difference in biomass between standard and high-residue rye, rye biomass in the high-residue treatment was relatively low. Greater suppression of *M. incognita* might be possible with rye residue levels > 4,500 kg ha^{-1}. Nevertheless, planting high-residue rye solely for suppression of *M. incognita* is probably not economical. Based on several studies throughout the southeastern U.S., Price et al. (2016) calculated that cotton yield increases between 69 to 83 kg ha^{-1} (at a lint price of US $2.32 kg^{-1}) above yields following fallow were needed to offset the costs of planting high-residue cover crops. However, if farmers plant high-residue rye to improve soil structure, moisture retention, and weed control, then they might benefit also from lower populations of *M. incognita*.

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DISCLAIMER

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

REFERENCES

Dabney, S.M., J.A. Delgado, and D.W. Reeves. 2001. Using winter cover crops to improve soil and water quality. Commun. Soil Sci. Plant Anal. 32:1221–1250.

Ibrahim, I.K.A., S.A. Lewis, and D.C. Harshman. 1993. Host suitability of graminaceous crop cultivars for isolates of *Meloidogyne arenaria* and *M. incognita*. J. Nematol. 25:858–862.

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

Johnson, A.W., and R.E. Motsinger. 1990. Effects of planting date, small grain crop destruction, fallow, and soil temperatures on the management of *Meloidogyne incognita*. J. Nematol. 22:348–355.

Lu, Y.C., K.B. Watkins, J.R. Teasdale, and A.A. Abdul-Baki. 2000. Cover crops in sustainable food production. Food Rev. Intern. 16:121–157.

McSorley, R., and R.N. Gallaher. 1994. Effect of tillage and crop residue management on nematode densities on corn. J. Nematol. 26:669–674.

Meyer, S.L.F., C.P. Rice, and I.A. Zasada. 2009. DIBOA: Fate in soil and effects on root-knot nematode egg numbers. Soil Biol. Biochem. 41:1555–1560.

Minton, N.A. 1992. Nematode management in minimum-till soybean with resistant cultivars, rye rotation, and aldicarb. Nematropica. 22:21–28.

Minton, N.A., and K. Bondari. 1994. Effects of small grain crops, aldicarb, and *Meloidogyne incognita* resistant soybean on nematode populations and soybean production. Nematropica. 24:7–15.

Minton, N.A., and M.B. Parker. 1987. Root-knot nematode managment and yield of soybean as affected by winter cover crops, tillage systems, and nematicides. J. Nematol. 19:38–43.

Perez, F.J., and J. Ormeno-Nunez. 1991. Difference in hydroxamic acid content in roots and root exudates of wheat (*Triticum aestivum* L) and rye (*Secale cereale* L)—possible role in allelopathy J. Chem. Ecol. 17:1037–1043.

Price, A.J., K.S. Balkcom, A.S.Culpepper, J.A. Kelton,R.L. Nichols, and H. Schomberg. 2011. Glyphosate-resistant Palmer amaranth: A threat to conservation tillage. J. Soil Water Conserv. 66:265–275.

Price, A.J., C.D. Monks, A.S. Culpepper, L.M. Duzy, J.A. Kelton, M.W. Marshall, L.E. Steckel, L.M. Sosnoskie, and R.L. Nichols. 2016. High-residue cover crops alone or with strategic tillage to manage glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) in southeastern cotton (*Gossypium hirsutum*). J. Soil Water Conserv. 71:1–11.

Reeves, D.W. 1994. Cover crops and rotations. p. 125–172 *In* J.L. Hatfield and B.A. Stewart (ed.), Crop Residue Management. Lewis Publ., Boca Raton, FL.

Rice, C.P., G.M. Cai, and J.R. Teasdale. 2012. Concentrations and allelopathic effects of benzoxazinoid compounds in soil treated with rye (*Secale cereale*) cover crop. J. Agric. Food Chem. 60:4471–4479.

Teasdale, J.R., and C.L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agron. J. 85:673–680.

Teasdale, J.R., and C.L. Mohler. 2000. The quantitative relationship between weed emergence and the physical properties of mulches. Weed Sci. 48:385–392.

Timper, P., R.F. Davis, and P.G. Tillman. 2006. Reproduction of *Meloidogyne incognita* on winter cover crops used in cotton production. J. Nematol. 38:83–89.

Timper, P., R.F. Davis, T.M. Webster, T.B. Brenneman, S.L.F. Meyer, I.A. Zasada, G. Cai, and C.P. Rice. 2011. Response of root-knot nematodes and Palmer amaranth to tillage and rye green manure. Agron. J. 103:813–821.

Tyler, D., P. Denton, and D.W. Reeves. 2000. Cover crop management in cotton. p. 103–107 *In* R.Reeder (ed.) Conservation Tillage Systems and Management. 2nd ed. MidWest Plan Service 45, Iowa State Univ., Ames, IA.

Webster, T.M., D.B. Simmons, A.S. Culpepper, T.L. Grey, D.C. Bridges, and B.T. Scully. 2016. Factors affecting potential for Palmer amaranth (*Amaranthus palmeri*) suppression by winter rye in Georgia, USA. Field Crops Res. 192:103–109.

Yenish, J.P., A.D. Worsham, and W.S. Chilton. 1995. Disappearance of DIBOA-gluciside, DIBOA, and BOA from rye (*Secale cereale* L.) cover crop residue. Weed Sci. 43:18–20.

Zasada, I.A., S.L.F. Meyer, J.M. Halbrendt, and C. Rice. 2005. Activity of hydroxamic acids from *Secale cereale* against the plant-parasitic nematodes *Meloidogyne incognita* and *Xiphinema americanum*. Phytopathology. 95:1116–1121.

Zasada, I.A., C.P. Rice, and S.L.F. Meyer. 2007. Improving the use of rye (*Secale cereale*) for nematode management: potential to select cultivars based on *Meloidogyne incognita* host status and benzoxazinoid content. Nematology. 9:53–60.