Suitability of a Wheat-Sorghum, Double-Crop Rotation to Manage *Criconemella xenoplax* in Peach Production

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ABSTRACT

Nyczepir, A. P., Bertrand, P. F., and Cunfer, B. M. 1996. Suitability of a wheat-sorghum, double-crop rotation to manage *Criconemella xenoplax* in peach production. Plant Dis. 80:629-632.

Twenty-one sorghum cultivars were evaluated for host suitability to the ring nematode *Criconemella xenoplax* in the greenhouse. No *C. xenoplax* were detected on peach in soil previously planted to GK8172C, Funks G-522DR, Jacques-505, McCurdy M51YG, Northrup King NK2660, or Northrup King NK-Savannah 5. Additionally, the effects of 1-, 2-, and 3-year wheat-sorghum and wheat-fallow preplant double-crop rotations for the management of *C. xenoplax* were studied from 1990 to 1993 in a field experiment in central Georgia. The field site had a previous history of peach tree short life and was heavily infested with *C. xenoplax*. All wheat-sorghum and wheat-fallow rotations suppressed population densities of *C. xenoplax* compared with 3 years of continuous peach ($P \leq 0.05$). One year of wheat-fallow did not suppress *C. xenoplax* population densities as low as did 1 year of wheat-sorghum. No differences in suppression of *C. xenoplax* population density were detected among the 1, 2, and 3 years of wheat-sorghum rotation. A wheat-sorghum rotation has potential as a preplant strategy to manage *C. xenoplax* in peach orchards in the southeastern United States.

Additional keywords: *Prunus persica, Sorghum vulgare, Triticum aestivum*

Peach tree short life (PTSL) is a major problem for peach growers in the southeastern United States. Trees affected by PTSL usually die before the orchard reaches full productivity. In a recent tree-death survey (1980 to 1992), a total loss in potential income to South Carolina growers from PTSL was estimated at more than \$6 million annually (10). Management of the ring nematode *Criconemella xenoplax* (Raski) Luc & Raski (= *Mesocriconema xenoplax* (Raski) Loof & de Grisse) with pre- and postplant nematicides has reduced tree mortality from cold injury and bacterial canker (*Pseudomonas syringae* pv. *syringae*), two important causal agents of the sudden collapse of peach (*Prunus persica* (L.) Batsch) trees associated with the PTSL syndrome (3,14,17). In the past, management of *C. xenoplax* was accomplished with the use of the inexpensive and highly efficacious fumigant nematicide 1,2-dibromo-3-chloropropane (DBCP) (11). However, the U.S. Environmental Protection Agency suspended registration of DBCP as a soil fumigant for all crops in 1981 (9). Currently, there are two soil fumigants (methyl bromide and 1,3-dichloropropene) registered for preplant treatment and one nonfumigant nematicide (fenamiphos) is registered for postplant treatment for control of nematodes on peach in Georgia and South Carolina; however, the 1990 Clean Air Act proclaimed that use of methyl bromide would be terminated by 2001 (18). Fewer nematode management options may be available to growers in the future.

Alternative approaches to chemical control for nematode management need to be explored. Crop rotation is one option. Nematode management with crop rotation has been most successful when applied to annual crops rather than to perennials such as peach (7,15); however, rotation as a preplant management strategy for nematodes on peach may have a role in an integrated pest management program. Greenhouse and small plot field trials showed that certain small grain crops planted before peach trees significantly reduced the population density of *C. xenoplax* (12). Wheat (*Triticum aestivum* L. emend. Thell) cultivar Stacy suppressed the population density of *C. xenoplax* after 3 years under field conditions (12). In the same study, companion summer crops or management practices that also might suppress *C. xenoplax* were found to be unsuitable for the following reasons: (i) fallow, because of the possible surface soil erosion that would result; (ii) weeds, because some weeds are hosts to *C. xenoplax* (19); and (iii) soybean (*Glycine max* (L.) Merr.), because all soybean cultivars tested were good hosts for *C. xenoplax* (12). Sorghum (*Sorghum vulgare* Pers. cv. Pioneer 8333), another crop to follow winter wheat, was also a host for *C. xenoplax*, but information on other cultivars is unknown (12).

The objectives of this study were to determine the host suitability of sorghum cultivars to *C. xenoplax* and to evaluate the effects of 1-, 2-, and 3-year wheat-sorghum and wheat-fallow rotations for suppression of *C. xenoplax* under field conditions.

MATERIALS AND METHODS

Evaluation of sorghum cultivars. Twenty-one sorghum cultivars were evaluated for host suitability to *C. xenoplax* in the greenhouse (Table 1). Two-week-old Nemaguard peach seedlings or 8-day-old sorghum seedlings were planted singly in 15-cm-diameter plastic pots containing 1,500 cm^3 steam pasteurized loamy sand (86% sand, 10% silt, 4% clay; pH 6.1; 0.54% organic matter). The susceptible cultivar Nemaguard was used to verify nematode infectivity. Pots without plants were designated as a fallow treatment. Approximately 5 days later, the soil in each pot was infested with 2,000 *C. xenoplax* adults and juveniles in 40 ml of water (12). The nematode isolate was obtained from an orchard previously diagnosed as a PTSL site in Byron, GA, and cultured on Nemaguard peach in the greenhouse. Nematodes were extracted from the soil medium by centrifugal-flotation (8). Ten replications of each plant species and five replications of fallow were arranged in randomized complete blocks on benches in an air-conditioned greenhouse (27 ± 5°C). Plants were watered as needed and fertilized every 2 weeks (13). Approximately 6 months after soil infestation, all test treatments were harvested and nematodes extracted from a 100-cm^3 soil subsample with a semiautomatic elutriator (5) and centrifugal-flotation (8). Nematode counts were adjusted for efficiency (67%) of extraction procedures. The nematode reproduction factor (Rf = final population density [Pf] of all life stages divided by initial population density [Pi]) was calculated as a measure of host suitability

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Accepted for publication 2 February 1996.

Publication no. D-1996-0329-04R

among the different plant treatments. Cultivars were grouped into three classifications based on the nematode *Rf* rating, as follows: nonhost, $Rf = 0$; poor host, $Rf = 0.01$ to 1.99; and suitable host, $Rf > 2$. Gravid females were also counted as a measure of reproduction. The experiment was repeated once (test 2) with the addition of Stacy wheat, as a poor host of *C. xenoplax* (Table 1).

Peach bioassay. Soil remaining after each sorghum evaluation experiment was composited by treatment, mixed, and placed into 15-cm-diameter plastic pots. One Nemaguard peach seedling was planted in each pot for a bioassay of levels of *C. xenoplax* not detectable by elutriation and centrifugal-flotation. Treatments were replicated four times in test 1 and five times in test 2, and the nematodes were extracted from the soil and counted after approximately 6 months as described for evaluation of sorghum cultivars.

Field trials. Stacy wheat (12) and NK2660 sorghum, one of six cultivars rated as a nonhost to *C. xenoplax* in the greenhouse tests (Table 1), were compared with Nemaguard peach rootstock in a rotation experiment designed to investigate the effect of rotation on *C. xenoplax*. Nemaguard peach rootstock served as the control because it is a good host of *C. xenoplax* (1). The experiment was initiated in November 1990 in a commercial peach orchard near Fort Valley, GA. The study was conducted on a sandy loam soil (80% sand, 8% silt, 12 % clay; pH 5.5; 0.87% organic matter) with a previous history of PTSL. For many years, peaches were commercially produced on this site until the trees were removed in August to September 1990 following severe losses due to PTSL.

The test site was subsoiled, disked, and rotovated before wheat planting in December 1990, and rotovated when wheat-sorghum and wheat-fallow plots were established in subsequent years. Plots consisted of seven treatments, as follows: 3 years of continuous peach (P-P-P); 2 years of peach followed by either one complete annual cycle of wheat-sorghum (P-P-WS) or wheat-fallow (P-P-WF); 1 year of peach followed by either two complete cycles of wheat-sorghum (P-WS-WS) or wheat-fallow (P-WF-WF); and three complete cycles of wheat-sorghum (WS-WS-WS) or wheat-fallow (WF-WF-WF). Plot size was 19.5 × 6.1 m. Treatments were arranged in randomized complete blocks with six replications. Care was taken not to transport soil among the plots throughout the study. Wheat was seeded (134.7 kg/ha) with a seven-row drill with 17.8 cm between rows. Sorghum was planted at a rate of 6.3 kg/ha with a four-row drill in 1991 and a two-row planter in 1992 to 1993 in rows 0.91 m apart. Peach tree spacing was 4.8 m between trees with eight trees per plot. Tree removal and planting/harvest dates for subsequent wheat and sorghum treatment plots are summarized in Table 2. Wheat was harvested with a combine or sickle bar, excess straw was removed, and the remaining stubble was incorporated into the soil with a rotovator prior to sorghum planting. Sorghum was harvested by hand and the stubble was incorporated prior to wheat planting each year. All wheat, sorghum, and peach plots received annual applications of selected fertilizers and herbicides as recommended by the Georgia Cooperative Extension Service for the respective crops (2,4,6,16). Fertilizer was applied to the wheat-fallow plots at 455 kg/ha as 5-10-15 (N-P-K) at planting and topdressed with 68 kg/ha of N as ammonium nitrate (34-0-0) in the spring. Fertilizer rates for wheat that was double-cropped with sorghum were 568 kg/ha 5-

Table 1. Reproduction of *Criconemella xenoplax* on sorghum, wheat, and peach cultivars and resurgence in nematode population density on Nemaguard peach in soil previously planted to sorghum and peach in the greenhouse after 180 days

		Rf[t]		*Criconemella xenoplax* gravid females (No./100 cm³ soil)		Resurgence in *C. xenoplax* (No./100 cm³ soil)	
Plant species	Cultivar	Test 1[u]	Test 2[u]	Test 1[u]	Test 2[u]	Test 1[v]	Test 2[v]
Peach	Nemaguard	63.22[w]	21.03[w]	92[w]	239[w]	638[x]	3,422[x]
Wheat	Stacy	. . .[y]	0.01	. . .	0	. . .	. . .
Sorghum	GK552G	0.00 b[z]	0.01 b	0 b[z]	0	38 def[z]	12 b[z]
	GK712G	0.00 b	0.00 b	0 b	0	26 def	0 b
	GK802G	0.00 b	. . .	0 b	. . .	131 bcd	. . .
	GK8172C	0.00 b	0.08 a	0 b	0	0 f	0 b
	Dekalb DK66	0.00 b	. . .	0 b	. . .	11 def	. . .
	Dekalb DK60	0.00 b	0.00 b	0 b	0	4 ef	0 b
	Dekalb DK64	0.00 b	. . .	0 b	. . .	1,043 bc	. . .
	Funks G-522 DR	0.00 b	0.01 b	0 b	0	0 f	0 b
	Funks G-1711	0.00 b	. . .	0 b	. . .	686 ab	. . .
	Funks G-1602	1.56 a	. . .	15 a	. . .	2,899 a	. . .
	Jacques-505	0.01 b	0.00 b	0 b	0	0 f	0 b
	Jacques-8856-X	0.03 b	. . .	0 b	. . .	109 cdef	. . .
	McCurdy M747	0.00 b	. . .	0 b	. . .	349 cde	. . .
	McCurdy M745	0.01 b	0.00 b	0 b	0	86 def	0 b
	McCurdy M51YG	0.00 b	0.00 b	0 b	0	0 f	0 b
	McCurdy M57YG	0.00 b	0.00 b	0 b	0	243 def	0 b
	Northrup King X8731	1.32 a	. . .	14 a	. . .	3,788 a	. . .
	Northrup King NK2660	0.00 b	0.00 b	0 b	0	0 f	0 b
	Northrup King X8539	0.00 b	. . .	0 b	. . .	41 cdef	. . .
	Northrup King X8642	0.00 b	0.00 b	0 b	0	8 def	192 a
	Northrup King NK-Savannah 5	0.00 b	0.00 b	0 b	0	0 f	0 b
	Combined	0.14	0.01	<1	0	451	17
Fallow		0.00	0.05	0	0	19	0

[t] Rf = reproductive factor (Pf/Pi), where Pi = initial population density of 133 *C. xenoplax* per 100 cm³ soil.

[u] Data are means of 10 replicates except fallow, which had five replicates.

[v] Data are means of four and five replicates for tests 1 and 2, respectively.

[w] The single-degree-of-freedom comparison between the means for peach vs. combined sorghum cultivars; peach vs. wheat; and peach vs. fallow was highly significant ($P \leq 0.01$).

[x] The single-degree-of-freedom comparison between the means for peach vs. combined sorghum cultivars and peach vs. fallow was highly significant ($P \leq 0.01$).

[y] . . . = Cultivar not included in test.

[z] Means within a plant species and column followed by the same lower case letter are not different ($P \leq 0.05$) according to Fisher's protected least significant difference.

10-15 at planting and topdressed with 75 kg/ha of N as 34-0-0 in the spring. Sorghum plots received 1,818 kg/ha, with one-third N (5-10-15) applied preplant and two-thirds N topdressed as 34-0-0 at the five- to six-leaf stage. Fertility rates for peach trees were according to the schedule outlined for nonbearing trees with 10-10-10 and 34-0-0 (6). Dolomitic lime (2,241 kg/ha) was applied to the entire plot in October 1991 in order to increase the soil pH to 6.0, which is recommended for proper peach and small grain growth in the Southeast (4,6,16). Weeds in wheat plots were controlled with thifensulfuron-methyl/tribenuron-methyl (0.035 kg a.i./ha). Paraquat (0.78 kg a.i./ha) and oryzalin (4.5 kg a.i./ha) were used to control weeds in peach plots. Plots were hand weeded as required. Fallow plots were treated with glyphosphate (4.49 kg a.i./ha) as necessary to manage emerging weeds.

An estimate of the *Pi* of *C. xenoplax* was determined on 10 December 1990 from 10 soil cores (2.5 cm in diameter × 30 cm deep) collected arbitrarily throughout the test site. Nematode population densities were determined also on 17 June and 16 October 1991, 25 June and 14 October 1992, and 6 July and 14 September 1993 from eight soil cores collected arbitrarily throughout each small grain plot or one soil core collected from within the drip lines of each of the eight trees of each peach plot. The soil cores were composited by plot within each replicate, and the nematodes were extracted as described for evaluation of sorghum cultivars. Tree death resulting from cold injury and/or bacterial canker was recorded in the P-P-P cropping system to monitor PTSL in the site.

Statistics. Nematode data were transformed to $\log_{10}(x + 1)$ values, and subjected to analysis of variance with the general linear models (GLM) procedure of SAS (SAS Institute, Cary, NC). For the greenhouse tests, appropriate preplanned single-degree-of-freedom comparisons were used to detect differences among treatment means as follows: Nemaguard peach versus combined sorghum cultivars; peach versus wheat; and peach versus fallow. Means within a plant species were analyzed using Fisher's protected least significant difference (LSD) test. For the field test, appropriate single-degree-of-freedom comparisons were performed in 1991 (means following P-P-P, P-WF-WF, P-WS-WS, P-P-WF, and P-P-WS versus WF-WF-WF and WS-WS-WS rotation treatments) and in 1992 (means following P-P-P, P-P-WF, and P-P-WS versus P-WF-WF, P-WS-WS, WF-WF-WF, and WS-WS-WS rotation treatments) following a significant *F* test. In 1993, means for the various rotation treatments were separated by Fisher's LSD test. Actual numerical data were used for table presentation. Only significant differences ($P \leq 0.05$) will be discussed unless stated otherwise.

RESULTS AND DISCUSSION

Evaluation of sorghum cultivars. In both tests, Nemaguard peach supported greater reproduction and more gravid females of *C. xenoplax* than did the sorghum cultivars, Stacy wheat, or fallow soil treatments (Table 1). Funks G-1602 and Northrup King X8731 sorghum supported low numbers of gravid females (14 to 15/100 cm^3 soil), whereas other sorghum cultivars and Stacy wheat did not support gravid females.

Peach bioassay. Numbers of *C. xenoplax* were greater in soil previously planted to peach than for the sorghum combined and fallow treatments (Table 1). On sorghum, the greatest increase in *C. xenoplax* population occurred on Funks G-1602 and Northrup King X8731. No *C. xenoplax* were detected on peach in soil previously planted to GK8172C, Funks G-522DR, Jacques-505, McCurdy M51YG, Northrup King NK2660, or NK-Savannah 5 sorghum in either bioassay test. Cultivars of wheat (12) and sorghum differed in ability to suppress *C. xenoplax;* therefore, it is important to select a *C. xenoplax*–suppressive cultivar in order to obtain optimum results.

Field trials. The *Pi* of *C. xenoplax* for the six replications was 298/100 cm^3 soil (range 240 to 420), indicating that the nematode population density was relatively uniform throughout the test site. In October 1991, the population density of *C. xenoplax* was lower in the WF-WF-WF and WS-WS-WS following one complete rotation cycle than in the plots planted to peach (Table 3); however, no differences in nematode numbers were detected between WF-WF-WF and WS-WS-WS or among the peach plots (Table 3). Furthermore, the relative numbers of *C. xenoplax* in the peach plots declined after the first growing season compared with the *Pi*. One explanation for this decline on a known perennial host is that the root system was too limited to support many nematodes. However, the decline in nematode numbers was even greater following one cycle of wheat-sorghum or wheat-fallow, indicating the effectiveness of the wheat and sorghum in suppressing *C. xenoplax* population density. In October 1992, the nematode population densities were greater in all plots planted to peach (P-P-P, P-P-WF, and P-P-WS) following two complete rotation cycles than in those in the P-WF-WF, P-WS-WS, WF-WF-WF, and WS-WS-WS

Table 2. Planting/harvest schedule used in establishment of three wheat-fallow and wheat-sorghum double-cropping systems and peach on population density of *Criconemella xenoplax*, 1990 to 1993[v]

		Annual treatment cycles					
		Cycle 1		Cycle 2		Cycle 3	
Treatment[w]	Cultural practice	Wheat	Sorghum	Wheat	Sorghum	Wheat	Sorghum
WF-WF-WF	Plant	11 December 1990	...	13 November 1991	...	14 December 1992	...
	Harvest	13 June 1991	...	25 June 1992	...	17 June 1993	...
WS-WS-WS	Plant	11 December 1990	19 June 1991	13 November 1991	9 July 1992	14 December 1992	9 July 1993
	Harvest	13 June 1991	17 September 1991	25 June 1992	7 October 1992	17 June 1993	6 October 1993
P-WF-WF	Plant	Peach[x]		13 November 1991	...	14 December 1992	...
	Harvest			25 June 1992	...	17 June 1993	...
P-WS-WS	Plant	Peach[x]		13 November 1991	9 July 1992	14 December 1992	9 July 1993
	Harvest			25 June 1992	7 October 1992	17 June 1993	6 October 1993
P-P-WF	Plant	Peach[y]		Peach[y]		14 December 1992	...
	Harvest					17 June 1993	...
P-P-WS	Plant	Peach[y]		Peach[y]		14 December 1992	9 July 1993
	Harvest					17 June 1993	6 October 1993
P-P-P		Peach[z]		Peach[z]		Peach[z]	

[v] Commercial 6-year-old peach orchard (Goldcrest/Nemaguard) removed in August/September 1990.
[w] WF-WF-WF = wheat-fallow, 3 cycles; WS-WS-WS = wheat-sorghum, 3 cycles; WF-WF = wheat-fallow, 2 cycles; WS-WS = wheat-sorghum, 2 cycles; WF = wheat-fallow, 1 cycle; WS = wheat-sorghum, 1 cycle; and P-P-P = continuous peach. P = Flordaking/Nemaguard peach; W = Stacy wheat; S = NK2660 sorghum; and F = fallow.
[x] Peach trees planted on 18 February 1991 and removed 9 September 1991.
[y] Peach trees planted on 18 February 1991 and removed 14 September 1992.
[z] Peach trees planted on 18 February 1991 and removed 16 September 1993.

Table 3. Population densities of *Criconemella xenoplax*, as influenced by different cropping systems[u]

Crop sequence[v]			Number of *C. xenoplax* per 100 cm^3 soil[w]		
Cycle			1991	1992	1993
1	2	3	(16 October)	(14 October)	(14 September)
P	P	P	153[x]	399[y]	220 a[z]
P	P	WF	163	421	28 b
P	P	WS	103	424	5 c
P	WF	WF	138	38	3 c
P	WS	WS	133	20	0 c
WF	WF	WF	30	30	8 bc
WS	WS	WS	50	23	3 c

[u] Data are means of six replications per crop sequence.

[v] Crop sequence: P = Flordaking/Nemaguard peach; W = Stacy wheat; F = fallow; and S = NK2660 sorghum. Cycle 1 = 11 December 1990 to 17 September 1991; Cycle 2 = 13 November 1991 to 7 October 1992; and Cycle 3 = 14 December 1992 to 6 October 1993.

[w] Mean preplant soil population density of *C. xenoplax* was 298 adults and juveniles per 100 cm^3 soil.

[x] Single-degree-of-freedom comparisons of P-P-P, P-P-WF, P-P-WS, P-WF-WF, and P-WS-WS vs. WF-WF-WF, and WS-WS-WS are different ($P \leq 0.01$).

[y] Single-degree-of-freedom comparisons of P-P-P, P-P-WF, and P-P-WS vs. P-WF-WF, P-WS-WS, WF-WF-WF, and WS-WS-WS are different ($P \leq 0.01$).

[z] Crop sequence means followed by the same letter are not different ($P \leq 0.05$) according to Fisher's least significant difference.

rotations (Table 3). No differences in nematode numbers were evident among the four small grain treatment plots or among the peach plots. In September 1993, all wheat-fallow and wheat-sorghum rotations suppressed nematode population densities compared with P-P-P (Table 3) and substantiated a previous report regarding Stacy wheat (12) and the greenhouse evaluation of sorghum cultivars reported herein. Suppression of *C. xenoplax* appears to be the result of Stacy wheat being a poor host ($Rf = 0.01$) and NK2660 sorghum a nonhost ($Rf = 0.00$) to *C. xenoplax.* By the end of the second and third growing seasons, the population density of *C. xenoplax* was approximately 14 and 28 times greater on peach, respectively, than in the combined small grain rotations. Although all small grain rotations suppressed the population density of *C. xenoplax* more than continuous peach, some relatively low numbers of *C. xenoplax* were detected. One explanation may be the presence of alternative hosts, because complete weed control was not achieved even though herbicides were applied annually. One cycle of wheat-fallow (P-P-WF) was not as effective in suppressing numbers of *C. xenoplax* as one cycle of wheat-sorghum (P-P-WS), which suggests that sorghum has a more rapid effect on nematode suppression than does a single fallow season. No differences in nematode numbers were detected among the wheat-sorghum rotations or between the P-WF-WF and WF-WF-WF plots. Eighteen percent of the remaining trees in P-P-P system developed typical PTSL symptoms (3) in spring 1993 and died by June 1993, confirming that this test location was a PTSL site.

In summary, we demonstrated the effects and potential usefulness of a wheat-sorghum double-crop rotation system as a nonchemical management strategy to reduce the population density of *C. xenoplax* prior to planting peach. We have yet to determine how wheat-sorghum and wheat-fallow soil treatments compare with preplant soil fumigation with methyl bromide on incidence of PTSL.

ACKNOWLEDGMENTS

We thank Ray Adams, Lonnie Daniely, and John Youmans for technical assistance, Ray Miller for providing sorghum seeds for the greenhouse studies, Dewey Lee for technical advice on sorghum culture and management, and Al Pearson for providing land on which to conduct the field experiment.

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