Preplant Biofumigation with Sorghum or Methyl Bromide Compared for Managing *Criconeoides xenoplax* in a Young Peach Orchard

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ABSTRACT

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Sorghum as a preplant green manure biofumigant management system of *Criconeoides xenoplax* was investigated from 1998 to 2003. The study was conducted on a site infested with *C. xenoplax* and having a previous history of peach tree short life (PTSL). Plots consisted of five preplant treatments: (i) nonfumigated soil without tarp and urea, (ii) nonfumigated soil with tarp and urea, (iii) sorghum as a green manure without tarp and urea, (iv) sorghum as a green manure with tarp and urea, and (v) preplant methyl bromide fumigation. Sorghum as a green manure with and without tarp was comparable with methyl bromide fumigation in suppressing the population of *C. xenoplax* in the early stages of this experiment. Nematode population densities were suppressed 11 months longer in sorghum with tarp and urea plots than in sorghum without tarp and urea plots. However, nematode population densities in sorghum with tarp and urea plots were not suppressed as long as in fumigated methyl bromide plots (19 versus 24 months, respectively).

Additional keywords: ring nematode, *Sorghum vulgare*

The productive life span of peach trees does not exceed 6 to 10 years on some sites in the southeastern United States (3). Some tree death has been attributed to a disease complex termed peach tree short life (PTSL) (26). Typical external symptoms associated with this disease complex are similar to those of any plant deprived of an adequate and properly functioning root system (29). The final agents of tree death in the PTSL complex include bacterial canker (*Pseudomonas syringae* pv. *syringae* van Hall) (30), cold injury (22), or a combination of both. The ring nematode, *Criconeoides xenoplax* Raski (= *Mesocriconeuma xenoplax* (Raski) Loof & de Grisse), is the only plant-parasitic nematode that has been associated with predisposing trees to PTSL (19,20). Research has documented that management of *C. xenoplax* is essential for minimizing losses in peach to the PTSL syndrome (27). Additionally, Shepard et al. (28) reported that *C. xenoplax* was responsible for predisposing peach trees (cv. Suwanee)

to bacterial spot (*Xanthomonas arboricola* pv. *pruni*). Trees growing in *C. xenoplax*-infested soil exhibited more severe bacterial spot damage than trees in soil where the nematode populations had been suppressed.

Preplant nematicides for ring nematode control are available in the Southeast (18), but growers would prefer alternatives to chemical control that are less hazardous to humans, cheaper, and more environmentally safe. Research on alternatives to conventional nematicide application has concentrated in recent years on crop rotation, rootstock resistance, and biofumigation (13,15,16).

Biofumigation has been identified as the suppression of soilborne pests by volatile biocidal compounds, such as isothiocyanates, that are released into the soil when *Brassica* spp. rotation or green manure crops are hydrolyzed (11). Others have not confined the process of biofumigation to just *Brassica* spp.-related crops, but included other plants whose production of volatile substances in the biodecomposition of organic matter suppressed soilborne pathogens (2). Mojtahedi et al. (13) reported that certain sudangrass (*Sorghum sudanense* (Piper) Stapf) and sorghum-sudangrass hybrids (*S. bicolor* (L.) Moench × *S. sudanense*) were rated nonhosts for *Meloidogyne hapla* under greenhouse conditions. The nematode reproduction factor (R_f = final population density [Pf] of all life stages divided by initial

population density [Pi]) for *M. hapla* on all tested cultivars was $R_f < 0.1$. In contrast, the only cultivars in which *M. chitwoodi* did not reproduce in this greenhouse study were Trudan 8 (sudangrass hybrid) and Sordan 79 (sorghum-sudangrass hybrid). Under field conditions, Trudan 8 and Sordan 79 as green manure suppressed *M. chitwoodi* populations. Under laboratory conditions, *M. chitwoodi* J2 were more sensitive to Trudan 8 green manure (leaves) than egg masses. Sudangrass cultivars are useful as green manure, because they contain in their leaf tissue cell walls the cyanogenic glucoside dhurrin, which releases hydrogen cyanide upon degradation in the soil (31). Hydrogen cyanide is known to be toxic to nematodes (23). In Georgia, Nyczepir et al. (15) reported that several cultivars of sorghum tested suppressed populations of *C. xenoplax* in the greenhouse. Furthermore, numbers of *C. xenoplax* were undetectable in the bioassay test of soil which previously was planted to these sorghum cultivars and then replanted to a susceptible peach host. In a follow-up field study, it was demonstrated that a wheat-sorghum (*S. vulgare* Pers. cv. Northrup King 2660) rotation could be used as a potential preplant *C. xenoplax* management strategy in peach orchards.

The objective of this report was to evaluate the efficiency of sorghum as a green manure to reduce *C. xenoplax* populations in establishing a young peach orchard.

MATERIALS AND METHODS

Green manure establishment. NK2660 sorghum, a nonhost to *C. xenoplax* (15) was compared with preplant methyl bromide fumigation in a field experiment designed to investigate the effect of sorghum green manure on suppression of *C. xenoplax* populations. The experiment was initiated in July 1998 at the United States Department of Agriculture–Agricultural Research Service Southeastern Fruit and Tree Nut Research Laboratory in Byron, GA. The study was conducted on a Faceville sandy loam soil (78% sand, 14% silt, 8% clay; pH 5.1; 1.79% organic matter) with a previous history of PTSL. Peach trees had been growing on this site since 1995 and were removed in May 1998. Immediately following tree removal in May, the test site was subsoiled and rototated. The site had no previous history of

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sorghum production. Dolomitic limestone was broadcast (2,242 kg/ha) over the site on 24 July 1998 to increase the soil pH to 6.0. The test site then was rotated again before sorghum planting on 27 July 1998, and divided into six adjacent blocks each measuring 122 × 3.1 m with a 3-m buffer between blocks. Within each block there were five preplant soil treatments: (i) non-fumigated soil without tarp and urea (non-fumigated alone), (ii) nonfumigated soil with tarp and urea (nonfumigated-tarp-urea), (iii) sorghum as green manure without tarp and urea (sorghum alone), (iv) sorghum as green manure with tarp and urea (sorghum-tarp-urea), and (v) methyl bromide fumigation (MBr) which served as the positive control. Additional treatments could not be included for comparison in this study due to field space limitations. Plots within a block were 24.4 by 3.1 m. Treatments were arranged in a randomized complete block design with six blocks. Care was taken not to transport soil among the plots throughout all phases of the study. Sorghum was planted at a seeding rate of 4.4 kg/ha (= 135,905 seed/ha) with a four-row drill on 27 July 1998, in rows 0.38 m apart. Sorghum was chopped up using a flail mower and then incorporated into the soil using a rotovator on 23 September 1998. On 24 September 1998, urea at 168.3 kg/ha (46-0-0) was applied to the two treatments sorghum-tarp-urea and nonfumigated-tarp-urea, incorporated into the soil using a rotovator, then covered with a 4-mil clear polyethylene tarp (approximately 24.4 by 3.0 m). A tarp was used to prevent the rapid escape of any volatiles that may be produced from the degradation of the green sorghum manure. Urea was added to the soil of these two treatment plots because of the concern that the sorghum seeding rate would yield dry matter at only approximately 4,535 kg/ha, which was below the dry matter recommended rate of 18,145 to 22,680 kg/ha (R. Kabana, unpublished data). Therefore, the addition of a nitrogen source to the soil would narrow the C/N ratio of the sorghum material, which otherwise would have been too broad to stimulate microbial activity sufficiently to achieve complete decomposition of the plant tissue (6,24). Decomposition of the plant material as related to microbial activity is what results in the release of volatile compounds that are antagonistic against nematodes. Methyl bromide (98% methyl bromide, 2% chloropicrin) was applied (Blair Soil Fumigation Co., Pavo, GA) in a strip (3.1 m wide) under tarp (483 kg/ha) on 24 September 1998. Tarps also were installed in all respective treatment plots by Blair Soil Fumigation Company. Maximum and minimum soil temperature conditions at the time of treatment were 30 and 25°C and 29 and 26°C at the 10- and 20-cm depths, respectively. Soil moisture (at 10- to 15-cm depth) was adequate for fumiga-

tion such that, when the soil was compressed in the hand, it formed a ball that was broken easily with little disturbance. Tarps were removed from all plots on 13 November 1998 (50 days after treatment), at which time all plots were rated visually for percentage of vegetative weed growth (cover) present.

Sorghum plots received nitrogen (N) at 1,794 kg/ha, with one-third N applied preplant as 5-10-15 (N-P-K) and two-thirds N top-dressed as ammonium nitrate (34-0-0) at the five- to six-leaf stage (4).

Prefumigation *C. xenoplax* populations in soil were determined on 23 September 1998 from six soil cores (2.5 cm in diameter by 30 cm deep) collected within each plot throughout the test site and prior to incorporating the sorghum into the soil as a green manure. The six soil cores were composited by plot within each block for a total of 30 samples. The nematodes were extracted from a 100-cm³ soil subsample with a semi-automatic elutriator (5) and centrifugal flotation (9) and counted.

Green manure evaluation. Glyphosphate (4.49 kg a.i./ha) was applied in December 1998 to kill vegetation in all plots. All plots were planted to cv. Goldprince on Nemaguard rootstock at a tree spacing of 4.9 by 6.1 m in January 1999. Each preplant soil treatment plot had six trees, the outer two of which served as borders with the four center trees as the experimental unit. All trees received annual applications of fertilizer (10-10-10 and 34-0-0 N-P-K), insecticides, fungicides, and herbicides as recommended by the Georgia Cooperative Extension Service. All rates were according to the schedule outlined for nonbearing and bearing trees (7,8).

The preplant population density of *C. xenoplax* was determined on 28 January 1999 from six soil cores collected from within each plot throughout the test site as described for the prefumigation sampling in the green manure establishment section above. *C. xenoplax* postplant population density was determined also on 1 December 1999; 6 April, 27 September, and 18 December 2000; 27 March, 26 September, and 27 November 2001; 11 March, 10 September, and 3 December 2002; and 24 March 2003 from one soil core collected within the drip line of each of four test trees of each experimental unit. The four soil cores were composited and nematodes were extracted from a 100-cm³ subsample as described in the green manure establishment section above.

Beginning in 2001, trees were pruned in December to enhance the onset of peach tree short life (30). Trunk diameters were measured at 20.3 cm above the soil surface on 29 February 2000, 9 February 2001, 28 January 2002, and 4 February 2003. Tree mortality as a result of bacterial canker infection or cold injury was recorded on 3 May 2001, 22 April 2002, and 16 April 2003 to monitor PTSL in the site.

Statistics. Percentage of vegetative weed growth data were transformed to arcsine square root values and subjected to analysis of variance with the general linear models (GLM) procedure of SAS (SAS Institute, Cary, NC). Percentage of vegetative weed growth means were compared according to Fisher's protected least significant difference (LSD) test following a significant *F* test. Actual numerical percentages for vegetative weed growth data were used for presentation in table. Analysis of variance (ANOVA) also was performed to determine treatment effect on nematode and trunk diameter data. For the green manure evaluation test, nematode population and trunk diameter means were compared according to Fisher's protected LSD test following a significant *F* test. The proportion of peach tree survival within each experimental unit for the nonfumigated-alone, nonfumigated-tarp-urea, sorghum-alone, sorghum-tarp-urea, and preplant MBr soil fumigation treatments was analyzed for each sampling date with ANOVA. Only significant differences (*P* ≤ 0.05) will be discussed unless stated otherwise.

RESULTS AND DISCUSSION

Green manure establishment. The population density of *C. xenoplax*, prior to incorporating the sorghum green manure with and without tarp and urea and applying the methyl bromide into the soil, did not differ among the treatments (nonfumigated-alone = 50 *C. xenoplax*/100 cm³ of soil, nonfumigated-tarp-urea = 30 *C. xenoplax*/100 cm³ of soil, sorghum-alone = 13 *C. xenoplax*/100 cm³ of soil, sorghum-tarp-urea = 43 *C. xenoplax*/100 cm³ of soil, or MBr fumigation = 33 *C. xenoplax*/100 cm³ of soil), which indicated that the ring nematode was uniformly present throughout the test site. The day the tarps were removed from all respective plots in November 1998, percentage of weed cover was more abundant (*P* < 0.01) in the non-fumigated-alone or sorghum-alone plots than in the sorghum-tarp-urea, nonfumigated-tarp-urea, or fumigated plots (Table 1). One explanation for the lack of vegetative weed growth in the sorghum-tarp-urea or nonfumigated-tarp-urea treatment plots may be attributed to soil solarization. Soil solarization is the heating of soil under plastic to temperatures that are detrimental to soilborne pathogens and weeds (10). Soil temperatures during the 50-day tarping period at the 10- and 20-cm depths were such that the maximum and minimum temperatures were 29 to 25°C and 28 to 26°C, 25 to 21°C and 24 to 22°C, and 21 to 17°C and 21 to 18°C in September, October, and November, respectively. The duration and soil temperatures reached in this experiment may have been long and high enough to kill the weed seed, kill germinating seed, or both. Another explanation is that urea may have killed weed

seed directly. Urea has been observed to exhibit herbicidal properties when applied under plastic (W. Mitchem, *personal communication*). No differences in percentage of vegetative weed cover were detected among sorghum-tarp-urea, the nonfumigated-tarp-urea, or the fumigated plots. Methyl bromide, on the other hand, is a broad-spectrum fumigant that is known to have herbicidal properties, which explains the lack of weed growth in those treated plots (21).

Green manure evaluation. The nematode population density was greater ($P < 0.05$) in the nonfumigated-alone than in the sorghum-alone, sorghum-tarp-urea, or the MBr fumigated plots just prior to replanting peach trees in January 1999 (Table 2). These results substantiate the effec-

tiveness of sorghum as a nonhost for suppressing ring nematode populations (15). However, the mode of action in sorghum which suppresses ring nematode populations is unclear. One explanation may be that sorghum (*S. vulgare* Pers.) which contains the cyanogenic glycoside dhurrin (*p*-hydroxymandelonitrile-*B*-*D*-glucoside), that is primarily present in the epidermal cells of the leaf tissue, may be toxic to the nematode (1,12). It is known that when sorghum leaf tissue is incorporated into soil as a green manure the enzyme *B*-glucosidase catalyzes the hydrolysis of dhurrin. The dhurrin then is degraded enzymatically in the soil, resulting in the release of hydrogen cyanide (HCN). It is the HCN that is known to be toxic to *Meloidogyne* spp. (23,31). However, the HCN released in sorghum green manure may not be the compound responsible for suppressing ring nematode populations in the current study, because *C. xenoplax* is capable of producing the enzyme *B*-cyanoalanine synthase which detoxifies cyanide (17). It is the presence of this enzyme in *C. xenoplax* which partially explains why this ring nematode species is capable of feeding on peach roots without succumbing to the toxic effects from cyanide. A more plausible explanation for ring nematode suppression may be the possibility that, through decomposition of the sorghum organic matter, a shift in microflora community was created, leading to a biological equilibrium that may have affected nematode reproduction or development (24).

Fifteen months (December 1999) after incorporating the sorghum as a green manure, nematode populations were greatest in the nonfumigated-alone, nonfumigated-tarp-urea, or sorghum-alone plots than in the sorghum-tarp-urea or fumigated plots. Nematode populations were suppressed 11 months longer in sorghum-tarp-urea (December 1999) than in sorghum-alone plots (January 1999). It appears that covering the soil with a tarp and applying urea prolongs ring nematode suppression with the sorghum green manure more than with sorghum alone. No differences in *C. xeno-*

plax populations were detected between the sorghum-tarp-urea or fumigated plots. In April 2000 (19 months after incorporating the sorghum as a green manure), the *C. xenoplax* population density was higher in both nonfumigated and sorghum green manure plots than in the MBr-fumigated plots. No differences in nematode populations were detected among the nonfumigated and sorghum green manure plot treatments; indicating that the sorghum-tarp-urea treatment lost its efficacious impact against ring nematode 5 months earlier (April 2000) than MBr fumigation (September 2000). At 24 months after methyl bromide application (September 2000), fumigation effect on *C. xenoplax* population density did not differ from those in the other treatment plots. The benefit of preplant fumigation, one of the major components in the 10-Point Management Program (3) to control *C. xenoplax* in the PTSL disease complex, was substantiated in this current study. It is also important to note that it is not unusual for the effect of preplant fumigation to diminish over time. Zehr et al. (32) reported that managing *C. xenoplax* with the preplant fumigant 1,3-D was not effective beyond 2 years following treatment. Our results also substantiate those of Nyczepir et al. (14), who reported that a resurgence in the mean *C. xenoplax* population density on peach rootstock occurred within a 2-year period after a preplant broadcast treatment with methyl bromide. Ring nematode populations continued to increase in fumigated soil in subsequent sampling dates.

No differences in trunk diameter were detected among the nonfumigated, sorghum green manure, or fumigation treatments on all four sampling dates (*data not presented*). However, trees grown in sorghum-tarp-urea plots generally were larger in size on three of the four sampling dates, even though differences were not significant ($P > 0.05$).

Peach trees developed typical PTSL symptoms and died during the experiment. In May 2001 (28 months after trees were planted), more trees in the nonfumigated-alone plots developed PTSL symptoms and

Table 1. Percentage of vegetative weed cover growth in test plots as influenced by two sorghum green manure systems and preplant soil fumigation in field plots in Byron, GA

Treatment	Weed cover in plot (%) ^w
Nonfumigated-alone	98.3 a
Nonfumigated-tarp-urea ^x	0.8 b
Sorghum-alone ^y	100.0 a
Sorghum-tarp-urea ^{x,y}	0.2 b
MBr ^z	0.0 b

^w Data are means of six replications per treatment, showing percentage of weed cover in each respective treatment plot following tarp removal on 13 November 1998. Means within a column followed by the same letter are not different ($P < 0.01$) according to Fisher's least significant difference. Percentage data were analyzed using arcsine transformation and were back-transformed for presentation in this table.

^x Urea (46-0-0) was applied at a rate of 168.3 kg/ha, application date was 24 September 1998, and respective plots were covered with tarp. Tarps were removed on 13 November 1998.

^y Sorghum was planted at a seeding rate of 4.4 kg/ha on 27 July 1998, and then incorporated into the soil on 23 September 1998.

^z Methyl bromide (MBr; 98% methyl bromide and 2% chloropicrin) was applied at a rate of 483 kg/ha, application date was 24 September 1998, and tarps were removed on 13 November 1998.

Table 2. Populations of *Criconeoides xenoplax* on peach, as influenced by sorghum green manure and (or) fumigation, in field plots in Byron, GA^w

Treatment	<i>C. xenoplax</i> per 100 cm ³ soil											
	1999		2000			2001			2002		2003	
	28 Jan	1 Dec	6 Apr	27 Sep	18 Dec	27 Mar	26 Sep	27 Nov	11 Mar	10 Sep	3 Dec	24 Mar
Nonfumigated-alone	60 a	228 a	495 a	205 a	543 a	553 a	342 b	219 b	1,050 b	1,166 a	342 a	465 a
Nonfumigated-tarp-urea ^x	30 ab	238 a	325 a	375 a	500 a	528 a	68 b	155 b	588 b	65 a	130 a	288 a
Sorghum-alone ^y	13 b	213 a	363 a	178 a	265 a	610 a	35 b	143 b	568 b	495 a	303 a	282 a
Sorghum-tarp-urea ^{x,y}	23 b	98 b	405 a	80 a	395 a	773 a	340 b	398 b	908 b	330 a	590 a	505 a
MBr ^z	0 b	3 b	0 b	148 a	330 a	793 a	918 a	1,258 a	2,680 a	1,792 a	872 a	2,406 a

^w Data are means of six replications per treatment. Nematode means within a column followed by the same letter are not different ($P \leq 0.05$) according to Fisher's least significant difference.

^x Urea (46-0-0) was applied at a rate of 168.3 kg/ha, application date was 24 September 1998, and respective plots were covered with tarp. Tarps were removed on 13 November 1998.

^y Sorghum was planted at a seeding rate of 4.4 kg/ha on 27 July 1998, and then incorporated into the soil on 23 September 1998.

^z Methyl bromide (MBr; 98% methyl bromide and 2% chloropicrin) was applied at a rate of 483 kg/ha and application date was 24 September 1998. Tarps were removed on 13 November 1998.

Table 3. Effect of two sorghum green manure systems and preplant soil fumigation on development of peach tree short life (PTSL) in cv. Goldprince/Nemaguard in field plots in Byron, GA in 2001 to 2003^w

Treatment	Cumulative PTSL mortality (%)		
	3 May 2001	22 April 2002	16 April 2003
Nonfumigated-alone	29 a	54 a	79 ab
Nonfumigated-tarp-urea ^x	4 a	29 a	58 b
Sorghum-alone ^y	4 a	50 a	78 ab
Sorghum-tarp-urea ^{x,y}	12 a	46 a	62 b
MBr ^z	4 a	29 a	92 a

^v Data are means of six replications per treatment. Means within a column followed by the same letter are not different ($P \leq 0.05$) according to Fisher's least significant difference.

^x Urea (46-0-0) was applied at a rate of 168.3 kg/ha, application date was 24 September 1998, and respective plots were covered with tarp. Tarps were removed on 13 November 1998.

^y Sorghum was planted at a seeding rate of 4.4 kg/ha on 27 July 1998, and then incorporated into the soil on 23 September 1998.

^z Methyl bromide (MBr; 98% methyl bromide and 2% chloropicrin) was applied at a rate of 483 kg/ha; application date was 24 September 1998.

died than in the sorghum-alone, nonfumigated-tarp-urea, sorghum-tarp-urea, or MBr-fumigated plots even though differences were not significant ($P > 0.05$) (Table 3). In April 2003 (51 months after planting), a greater ($P < 0.05$) number of trees survived in the sorghum-tarp-urea or the nonfumigated-tarp-urea plots than trees in the fumigated plots. One explanation for why there was more tree mortality in the fumigated (92%) than in the sorghum-tarp-urea (62%) or nonfumigated-tarp-urea (58%) plots may be from greater induced tree stress caused by the increased population density of *C. xenoplax* in the fumigated plots over time. It has been reported that PTSL development is dependent upon cumulative population exposure of trees to *C. xenoplax* (16). In the present study, on every subsequent sampling date after 27 March 2001, the nematode population density in fumigated plots (92% tree mortality) was always higher than in the sorghum-tarp-urea (62% tree mortality) and nonfumigated-tarp-urea (58% tree mortality) treatment plots, even though differences in nematode populations among these three treatments were not always significant. One explanation for why *C. xenoplax* populations were lower in the sorghum-tarp-urea and nonfumigated-tarp-urea plots than in fumigated plots may be because of the presence of urea. Amending soil with ammonical nitrogen, such as urea, or with amendments that yield ammonia upon degradation are known to be effective in reducing nematode soil populations (25). Also, it is not uncommon to have differences in PTSL tree death among years when environmental conditions may seem similar and conducive for disease development. The use of Nemaguard rootstock in conjunction with December pruning will accelerate PTSL pressure on any experiment. This combination of poor PTSL management practices can minimize an otherwise useful management practice, such as preplant fumigation but, on the other hand is a useful short-term evaluation test procedure.

In summary, preplant sorghum as a green manure with and without tarping or urea was comparable with methyl bromide fumigation in suppressing the population of *C. xenoplax* in the early stages of this experiment. Nematode populations were suppressed 11 months longer in sorghum-tarp-urea plots than in sorghum-alone plots. However, nematode populations in sorghum-tarp-urea plots were not suppressed as long as in methyl bromide plots (19 versus 24 months, respectively). Furthermore, tree survival on this PTSL site was prolonged with the application of urea to the soil, which appeared to suppress *C. xenoplax* populations.

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