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Nematode Populations and Peach Tree Survival, Growth, and Nutrition at an Old Orchard Site

Dean R. Evert[1], Paul F. Bertrand[2], and 'Benjamin G. Mullinix, Jr.[3]
University of Georgia, Coastal Plain Experiment Station, Tifton, GA 31793

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Abstract. **Bahiagrass *(Paspalum notatum* Flugge CV. Paraguayan-22) growing under newly planted peach *[Prunus persica* (L.) Batsch.] trees severely stunted the trees. Neither supplemental fertilizer nor irrigating with two 3.8-liters·hour^{-1} emitters per tree eliminated tree stunting emitters were controlled by an automatic tensiometer set to maintain 3 kpa at a depth of 0.5 m under a tree in bahiagrass. Preplant fumigation with ethylene dibromide at 100 liters·ha^{-1}increased tree growth, but not tree survival. Fenamiphos, a nematicide, applied under the trees each spring and fall at a rate of 11 kg-ha -1 had no positive effect on tree survival, tree growth, or nematode populations. Bahiagrass tended to suppress populations of *Meloidogyne* spp. under the trees., *Meloidogyne* spp. were the only nematodes present that had mean populations > 65 per 150 cm^3 of soil. Leaf concentrations of several elements differed between trees growing in bahiagrass sod and in. bare ground treated with herbicides. Leaf Ca was low for all treatments in spite of a soil pH near 6.5 and adequate soil Ca. The severe stunting of trees grown in bahiagrass, irrespective of the other treatments, demonstrated that bahiagrass should not be grown under newly planted trees. The low populations of parasitic nematodes in bahiagrass showed that bahiagrass has potential as a preplant biological control of nematodes harmful to peach trees. Chemical name used: ethyl 3-methy1-4-(methylthio) phenyl (1-methylethyl) phosphoramidate (fenamiphos).**

The productive life of peach orchards in the southeastern United States is often limited by peach tree short-life (PTSL; life span < 8 years). The severity of PTSL usually increases each time a site is replanted with peach trees (Brittain and Miller, 1978; Nesmith et al., 1981). Most good orchard sites in the southeastern United States have been planted with peaches at least once, so control of PTSL becomes increasingly important. Field studies implicate ring nematodes *(Cnconemella* spp.) in PTSL (Nesmith et al., 1981; Wehunt et al., 1980), and greenhouse-grown peach trees developed short-life symptoms when C. *xenoplax* (Raski) Luc. and Raski were added to the soil (Nyczepir, 1983). Preplant fumigation (Sharpe et al., 1989; Wehunt et al., 1980; Zehr and Golden, 1986) and postplant nematicide treatments (Ritchie and Bennett, ,1985; Wehunt et al., 1980; Zehr et al., 1982) have increased survival and growth of trees.

Many fumigants and nematicides have been banned by the U.S. Environmental Protection Ageney because these chemicals persist in the environment or are suspected carcinogens. Biological controls, heat, and other nonchemical methods could become the only legal methods for controlling nematodes. Grasses suppress some nematodes that parasitize peach roots, but grasses have increased the frequency of diseases (Malvick and Moore, 1988). Grasses also reduce the growth of newly planted trees, probably by competing for available nutrients and moisture (Atkinson and White, 1986; Butler, 1986; Welker and Glenn, 1985, 1989). However, Glenn and Welker (1989) found that peach trees planted in a killed fescue sod grew better than those growing under conventional methods of site preparation. Hogue and Neilsen (1987) recently reviewed the literature on orchard floor management.

Bahiagrass and bermudagrass *[Cynodon dactylon* (L.) Pers.], two warm-season perennial grasses, usually decrease or eliminate populations of root-knot nematodes and some other nematodes that parasitize peach roots (McBeth, 1945; McGlohon et al., 1961). Bermudagrass, which is a major weed species in peach orchards in the southeastern United States, reduees growth of young peach trees (Welker and Glenn, 1989). Reduced tree growth may be due in part to allelopathy (Weller et al., 1985). Weller et al. also noted that common bermudagrass spreads rapidly and is difficult to confine.

Compared to bermudagrass, bahiagrass spreads much more slowly. Also, bahiagrass sod middles in an established peach orchard had lower populations of C. *xenoplax* than the herbicide-treated tree rows (Evert and Bertrand, 1987). Symptoms of PTSL occurred in the orchard; therefore, bahiagrass sod middles did not prevent short-life. The lower C. *xenoplax* populations in the bahiagrass sod indicated that bahiagrass directly under peach trees might control nematodes and reduce PTSL. Bahiagrass in the tree row would be acceptable if tree growth could be maintained by added fertilizer and irrigation.

This study examined the influence of preplant fumigation, drip irrigation, 'Paraguayan-22' bahiagrass sod under the trees, and postplant nematicide applications on nematode populations and peach tree survival, growth, and nutrition at an old orchard site.

Materials and Methods

Site preparation began Aug. 1983 with the removal of the second consecutive orchard at a site in Brooks County, Ga. The soil was classified as a Dothan loamy sand (0 to 0.5 m) over a sandy clay loam soil (fine-loamy, siliceous, thermic Plinthic Paleudults) (Calhoun, 1979). Trees in the previous orchard were 4.9 m apart in rows 5.5 m apart, with 2.4-m-wide herbicide-treated tree rows and 'Paraguayan-22' bahiagrass sod middles. Scattered populations of *Meloidogyne* spp., C. *omata*, and C. *xenoplax* were in the previous orchard. Symptoms of PTSL developed in the previous orchard.

The tree rows of the previous orchard were disk-harrowed to destroy existing vegetation and hasten breakdown of peach roots. New tree sites, which were halfway between the old tree sites in the old tree rows, were subsoiled and cross-subsoiled to a

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[1]Dept. of Horticulture
[2]Extension Plant Pathology, Rural Development Center.
[3]Statistical and Computer Services.

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depth of 0.4 m. The bahiagrass sod middles between the old tree rows were not disturbed.

The experimental design was a split-split plot in space with an additional split plot in time when samples were collected on more than one date (Steel and Torrie, 1960). The treatments, which consisted of preplant fumigation with ethylene dibromide (EDB), drip irrigation, and postplant treatments, were combined in a factorial structure. Main-plot treatments were EDB vs. no EDB arranged in randomized complete blocks with seven replications. Split-plot treatments were irrigation vs. no irrigation, and the split-split-plot treatments were the postplant treatments. The experimental unit for the split-split-plot treatments consisted of two adjacent data trees with a guard tree at each end of the plot.

EDB was applied on 31 Oct. 1983 at a rate of 100 liters -ha-l to the harrowed tree rows. The EDB was injected as Soilbrom-90 at a depth of 0.2 m through nine evenly spaced shanks, and a drag behind the shanks sealed the soil. The soil was 22 & 1C at 0.2 m during EDB application.

Peach trees, Louisiana selection L71-A73-21 on Lovell seedling rootstock, were planted Jan. 1984. The trees were not irrigated in 1984. Two 3.8-liters·h^{-1} emitters per tree were installed June 1985. The emitters were placed in the tree row at 1 and 1.5 m on either side of each irrigated tree. Soil moisture for the entire orchard was controlled by one switching-tensiometer that was in bahiagrass in the tree row near the center of the orchard. The tensiometer sensor was located 0.5 m below the soil surface and 0.5 m beyond an emitter that was 1, m from a tree. The tensiometer was set to maintain a water potential of 3 kPa, which produced good tree growth in the previous orchard at the site.

Postplant treatments were mowed bahiagrass sod, bare ground, and bare ground plus applications of the nematicide fenamiphos. 'Paraguayan-22' bahiagrass was seeded under the trees at 11 kg·ha^{-1} and mowed at a height of 0.1 m with a swing-arm mower at least monthly during the growing season. The bare ground was maintained by applying the herbicides 4-chloro-5-(methylamino)-2-(3-(tifluoromethyl)phenyl)-3(2H-pyridazinone (nonflurazon), 6-chloro-N,N'-diethyl-l,3,5-triazine-2,4-diamine (simazine), 5-chloro-3-(1,1-dimethylethyl)-6-methyl-2,4-(lH,3H)-pyrimidinedione (terbacil), N'-(3,4-dichlorophenyl)-N,N-dimethylurea (diuron), (±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy] propanoic acid (fluazifop), and 1, 1'-dimethyl-4,4'-bipyridinium ion (paraquat) in the tree row at the rates and times recommended by the Univ. of Georgia Cooperative Extension Service (Murphy, 1986). Fenamiphos (Nemacur 3ED; Mobay Corp., Kansas City, Me.) was sprayed in the tree row at 11 kg-ha-l in 470 liters of spray/ha each spring and fall.

All newly planted trees were fertilized with 1.1 kg 10N-4.3P–8.3K/tree as recommended by the Univ. of Georgia Cooperative Extension Service (Plank, 1989a, 1989b), and trees received 0.6 kg 33N–0P–0K/tree in May and again in July. In late Jan. 1985, 280 kg 10N-4.3P-8.3K/ha was banded under all trees. Applications of 85 kg of 33N–0P-0K/ha were banded under all trees in May and July 1986. Additional fertilizer was applied in 1986 and 1987 to the trees in bahiagrass because those trees had weak shoot growth and light-green leaves. On 4 June 1986, 280 kg of 16N–0P–0K/ha was banded under the trees in bahiagrass, and on 28 May 1987,287 kg of 10N-4.3P-8.3K/la was banded under the trees.

Trunk diameter was measured at a height of 0.1 m each fall from 1984 to 1988. Trunk cross-sectional area (TCA) was calculated from the diameter by assuming a cylindrical trunk. Total yield was measured in a once-over harvest on 15 June 1987 when the trees were ready for the first commercial harvest. Mean fruit weight was determined from 20 fruit/tree. Frost destroyed the crop in 1985 and 1986, and a grower-cooperator harvested the trees in 1988 by mistake.

Nematode populations in the top 0.3 m of soil were sampled just before the application of fenamiphos every spring and fall from Apr. 1984 to Sept. 1987. Nematode population densities per 150 cm^3 were determined by the Hematology Lab., Univ. of Georgia Cooperative Extension Service, using the procedure of Jenkins (1964). The nematodes identified were *C. ornata* (Raski) Luc. and Raski, C. *xenoplax*, *Helicotylenchus* and *Scutellonema* spp. combined, *Hoplolaimus* spp., *Meloidogyne* spp., *Parathrichodorus christiei* (Allen) Siddiqi, *Pratylenchus* spp., *Tylenchorhynchus claytoni* (Steiner), and *Xiphinema* spp.

Soil samples were collected Aug. 1985 and 1986 and analyzed for pH, P, K, Ca, and Mg. Leaf samples were collected Aug. 1985 and 1986 and July 1987 and analyzed for N, P, K, Ca, Mg, Mn, Fe, Al, B, Cu, and Zn. Soil and leaf analyses were done by the Soil Testing and Plant Analysis Lab., Univ. of Georgia Cooperative Extension Service.

Data analyses used PROC GLM and PROC STEPWISE of SAS (SAS Institute, 1985). Nematode population counts and trunk areas were log-transformed to stabilize the variance in the data analyses. Means of transformed data were back-transformed for presentation. Unbiased estimates of back-transformed nematode population means (count data) were calculated by applying the correction introduced by Thoni (1969). Elements with a significant association with the TCA were identified using the step-wise regression procedure of SAS (SAS Institute, 1985).

Results and Discussion

Nematode populations. Populations of *Helicotylenchus* and *Scutellonema* spp. combined, *Hoplolaimus* spp., *Parathrichodorus christiei*, *Pratylenchus* spp., *Tylenchorhynchus claytoni*, and *Xiphinema* spp. averaged < 1 per 150 cm^3 and were not investigated further. Of these species, only *Pratylenchus* spp. are known to damage peach trees, and *Pratylenchus* spp. are not a common problem in Georgia (Bertrand and Nyczepir, 1989).

Populations of *Meloidogyne* spp. averaged > 65 per 150 cm^3 of soil; irrigation had no effect on their average population. The average population of *Meloidogyne* spp. was independent of EDB fumigation (Table 1); EDB fumigation did lower populations *of Meloidogyne* spp. in Oct. 1984, Mar. 1985, and Sept. 1986; i.e., on three of the eight sampling dates (Table 2). EDB reduced the *Meloidogyne* spp. before tree planting, and the populations redeveloped as the peach roots grew.

The average populations of *Meloidogyne* spp. varied with postplant treatment, but the effect of postplant treatment depended on date (Table 1). Bahiagrass plots had lower *(P =* 0.05, Tukey's test) populations of *Meloidogyne* spp. (32 per 150 cm^3) than bare ground both with (44 per 150 cm^3) and without fenamiphos (311 per 150 cm^3) only in Oct. 1984, the year of planting. *Meloidogyne* spp. populations were equivalent under sod and bare ground on all later dates (data not shown). Bahiagrass is a poor host of *Meloidogyne* spp. (McGlohon et al., 1961), and *Meloidogyne* spp. probably multiplied on the roots of the growing peach trees.

Although C. *xenoplax* populations did not differ with any treatment or combination of treatments (data not shown), their populations were analyzed in detail because of the known as-

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Table 1. Preplant EDB fumigation, irrigation, postplant treatment, and date effects on nematode populations per 150 cm^3 of soil in a former peach orchard.

Treatment	*Meloidogyne* spp.	*Criconemella ornata*
Preplant EDB fumigation (E)		
No	78 a[z]	9 a
Yes	61 a	5 b
Irrigation (I)		
No	59 a	7 a
Yes	80 a	6 a
Postplant treatment (P)		
Sod[y]	53 b	14 a
Bare,	94 a	5 b
Bare +	66 ab	4 b
Date (D)		
Apr. 1984	1 e	10 a
Oct. 1984	94 bcd	4 ab
Mar. 1985	41 d	8 ab
Oct. 1985	307 ab	4 ab
Apr. 1986	385 a	3 b
Sept. 1986	235 abc	9 a
Mar. 1987	43d	7 ab
Sept. 1987	79 cd	10 a
Significant interactions(*P* = 0.05)	P × D E × D	P × D

[z]Letters indicate significance at *P* = 0.05 with Tukey's test. Means of 56 observations for postplant treatments and 84 observations for other treatments.
[y]Sod, Bare, and Bare + indicate postplant treatments: bahiagrass sod, bare ground, and" bare ground plus fenamiphos, respectively.

Table2. Nematode populations per 150 cm^3 of soil by date for *Meloidogyne* spp. with preplant EDB fumigation and for *Criconemella ornata* with postplant treatments in a peach orchard.

	Preplant EDB fumigation			Bare ground	
Date	No	Yes	Sod	Control	Fenamiphos
Apr. 1984	1 a[z]	1 a	8 a[z]	14 a	9 a
Oct. 1984	146 a	57 b	13 a	2 b	1 b
Mar. 1985	72 a	22 b	23 a	4 b	4 b
Oct. 1985	285 a	306 a	12 a	3 b	2 b
Apr. 1986	466 a	295 a	4 a	3 a	2 a
Sept. 1986	309 a	166 b	16 a	8 ab	6 b
Mar. 1987	29 a	59 a	29 a	2 b	5 b
Sept. 1987	62 a	93 a	15 a	14 a	4 b

[z]Letters within a row indicate differences for preplant fumigation and for postplant treatment at *P* = 0.05 with Tukey's test. Treatment means are based on 42 observations for *Meloidogyne* spp. and 28 observations for C. *ornata.* Data were log-transformed for analysis, and means were back-transformed for presentation with an adjustment for the bias of the log transformation (see text for details).

sociation of this species with PTSL (Nyczepir, 1983). Populations of C. *xenoplax* averaged < 1 per 150 cm^3 of soil for all treatments. The maximum C. *xenoplax* population was 116 per 150 cm^3 in a sample collected Mar. 1985. This sample came from bare ground that was not fumigated with EDB before tree planting but was irrigated and treated with fenamiphos afterward. This combination of no EDB, irrigation, and fenamiphos also produced the maximum average population for C. *xenoplax* of 1.4 per 150 cm^3 on Apr. 1984. On all other dates, this treatment combination had an average *C. xenoplax* population of <0.32 per 150 cm^3. *Criconemella xenoplax* populations failed to increase with time for this treatment combination—indeed, for any treatment combination in this orchard; apparently something in the orchard kept C. *xenoplax* populations from increasing on the susceptible peach roots. Mowing the sod middles spread bahiagrass clippings under the trees, and it is tempting to speculate that these clippings contained something that suppressed C. *xenoplax.*

The C. *ornata* population averaged 6.4 per 150 cm^3, which was ≈ 20 times the average population of C. *xenoplax. The* increased C. *ornata* population was expected because C. *ornata* parasitizes grass roots not peach roots (Ratanaworabhan and Smari, 1970). Similar results have been previously reported for bahiagrass sod in a peach orchard (Evert and Bertrand, 1987). The maximum average population of C. *ornata* for any treatment combination was 22.4 per 150 cm^3 on Mar. 1985 for sod without EDB or irrigation.

Preplant fumigation with EDB decreased the average population of C. *ornata* by 44% relative to sites without EDB (Table 1). Growing bahiagrass in the row after tree planting increased the average population of C. *ornata* ≥ *180%* relative to bare ground with and without fenamiphos (Table 1). Although sod increased the average population of C. *ornata*, the effect of bahiagrass sod and fenamiphos on C. *ornata* populations varied with date (Table 1). Populations of C. *ornata* for sod equaled or exceeded those for bare ground both with and without fenamiphos on all eight sampling dates (Table 2). Applying fenamiphos twice a year to bare ground lowered the population of C. *ornata* relative to untreated bare ground only in Sept. 1987.

The near zero populations of *Meloidogyne* spp. during the first growing season and the failure of initial populations of *C. xenoplax* to increase during the experiment suggest that bahiagrass has potential as a cleanup crop if no peach roots are present. The failure of populations of *C. xenoplax* to increase in the third consecutive peach orchard planted at the site also supports the idea that bahiagrass suppresses *C. xenoplax.* A bahiagrass sod between the tree rows of an existing orchard might effectively suppress *Meloidogyne* spp. and *C. xenoplax* populations in the middle of the sod so that new trees could be planted in the middle of the killed sod the year that the old orchard was removed.

Tree nutrition. Soil P, K, and Mg levels varied among the treatments (Table 3). Soil P, Ca, and Mg averaged 86, 1514, and 297 $kg \cdot ha^{-1}$, respectively. These values are in the high range for the coastal plain of Georgia, so no applications of these elements were recommended (Plank, 1989b). Soil K ranged from 118 to 178 $kg \cdot ha^{-1}$, which is in the medium to high range. The recommended annual application of K is 28 $kg \cdot ha^{-1}$ for soil K in the medium range and 56 $kg \cdot ha^{-1}$ for the high range. Soil pH for all treatments ranged from 6.6 to 6.9, which was above the recommended range of 6.0 to 6.5 for Georgia. This recommended pH range is based on economic return rather than a physiological response of the plant (Plank, 1989b).

Soil P, K, and Mg were higher for bare ground + fenamiphos than for sod (Table 3); for soil K, the effect of postplant treatment varied with irrigation and year. Soil P was higher with EDB than without and lower with irrigation than without, but the response of soil P to each treatment depended on the other treatment. Details of the treatment interactions are not presented because the combined effects of the treatments and their interactions explained <20% ($r^2 < 0.2$) of the total variability in

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Table 3. EDB fumigation irrigation, postplant treatment, and year effects on soil pH and soil fertility in a peach orchard.

Treatment	pH	P	K	Ca	Mg
		[kg·ha^{-1})			
Preplant EDB fumigation (E)					
No	6.6 a[z]	84 a	142 a	1377 a	270 a
Yes	6.9 a	89 b	154 a	1651 a	324 a
Irrigation (I)					
No	6.7 a	91 a	147 a	1479 a	290 a
Yes	6.7 a	82 b	149 a	1549 a	304 a
Postplant treatment (P)					
Sod[y]	6.8 a	78 b	133 b	1500 a	286 b
Bare	6.7 a	89 a	147 b	1482 a	290 b
Bare +	6.7 a	91 a	164 a	1562 a	316 a
Year (Y)					
1985	6.7 a	89 a	178 a	1640 a	339 a
1986	6.8 a	85 a	118 b	1389 b	256 b
Significant interactions ($P = 0.05$)	P × Y	E × Y E × I	E × I I × P P × Y	---	---
r^2	0.16[x]	0.19	0.43	0.19	0.18

[z]Letters within treatments indicate significance at P = 0.05 with Tukey 's test. Means of 56 observations for postulant treatment and 84 observations for other treatments.

[y]Sod, Bare, and Bare+ indicate bahiagrass sod, bare grourid, and bare ground plus fenamiphos, respectively.

[x]Proportion of the total variability explained by the treatments and treatment combinations combined.

pH, P, Ca, and Mg. Soil K is not discussed for reasons that will be apparent when the elemental leaf concentrations are presented.

The average leaf concentrations of N, B, Ca, Fe, Cu, and Zn were sometimes outside of the sufficiency range for Georgia. Concentrations of leaf N and B were above the sufficiency range in 1985 (Plank, 1989a), while concentrations of leaf Ca, Fe, Cu, and Zn were below the sufficiency range in 1986 and 1987 (Table 4). Low concentrations of leaf Ca occurred in spite of a soil pH > 6.5 and a soil Ca level >1300 kg·ha^{-1}.

Leaf K, in contrast to soil K, was independent of all treatments and combinations of treatments (Table 4). Leaf concentrations of all elements other than K varied with year. There was a significant interaction between year and one of the other treatments for most elements.

The average leaf concentrations of all elements were independent of EDB fumigation, but in some years, leaf concentrations of Fe, Al, and Zn varied with EDB fumigation (Table 4). Preplant fumigation with EDB increased the leaf concentrations of Fe and Al in 1985 and 1987 but not in 1986, and preplant fumigation with EDB increased the leaf concentrations of Zn in 1985 but not in 1986 or 1987 (Table 5).

Leaf concentrations of N and B changed in response to irrigation (Table 4). The leaf concentration of N decreased ≈5% in response to irrigation, and this response was independent of the other treatments. The average concentration of B increased nearly 9% in response to irrigation; however, this response varied with year. Leaf concentrations of B averaged 4 mg·kg^{-1} more in irrigated than in control trees in 1986 and 1987 and were equivalent in 1985 (P < 0.05).

The average leaf concentrations of P and B varied with postplant treatment (Table 4). Leaf concentrations of P, like those of N, Ca, Fe, and Al, depended on both the postplant treatment and year. Variations in leaf B with postplant treatment were independent of year and averaged 3 to 4 mg·kg^{-1} more for trees in sod than in bare ground, either with or without fenamiphos.

Leaf N and P, which are mobile in the plant, first differed with postplant treatment in 1987 (Table 6). Leaf N in 1987 was lowest for trees in bahiagrass sod, intermediate for trees in bare ground with fenamiphos, and highest for trees in bare ground without fenamiphos. Leaf P in 1987 was higher for trees in sod than for trees in bare ground with or without fenamiphos.

Leaf concentrations of Ca and Al, which are relatively immobile in the plant, were lower in 1985 in trees in sod than in trees in bare ground with or without fenamiphos applications (Table 6). In 1985, concentrations of Fe, another immobile element, were lower in trees in sod than in trees in bare ground plus fenamiphos. The low concentrations of these three elements in the newly planted trees in sod might reflect a restricted root system with limited capability to take up moisture and nutrients. The pattern of lower leaf concentrations for trees in sod than in bare ground reversed for Fe in 1986 and tended to reverse for Ca and Al. All differences in leaf concentrations of Ca, Fe, and Al that were associated with sod disappeared in 1987.

Leaf Mg showed the most complicated response to the treatments of any element measured; concentrations of leaf Mg varied with combinations of irrigation, postplant treatment, and year (Table 4). However, concentrations of leaf Mg always ranged from 3.9 to 4.8 g·kg^{-1}, which was within the sufficiency range of 2.5 to 5 g·kg^{-1}. The significant interaction of irrigation, postplant treatment, and year occurred because concentrations of leaf Mg in nonirrigated trees tended to hold steady or increase from 1985 to 1987 when fenamiphos was applied and to decrease when no fenamiphos was applied (data not shown). Concentrations of leaf Mg did not differ among trees in the other combinations of irrigation, postplant treatment, and year (data not shown).

Others have reported that sod influences concentrations of leaf elements. Leaf N, Mg, Cu, and Zn varied in newly planted peach trees as the area free of tall fescue varied under the tree (Welker and Glenn, 1985). Leaf N, P, K, Ca, Mg, Mn, and Zn varied in newly planted peach trees as the density of common bermudagrass varied under the. trees (Weller et al., 1985). Concentrations of many leaf elements involved linear and quadratic changes as the density of common bermudagrass increased.

Tree death and growth. Trees died with typical symptoms of PTSL; i.e., collapse and death of the tree in the spring and growth of suckers from the rootstock. Irrigation had no effect on tree death, so data were combined for irrigated and nonirrigated trees (data not shown). All trees were alive at the end of the first growing (1984) (Fig. 1), so no intercept was included in the linear regression equations for cumulative tree death by year. The coefficients of quadratic and cubic regression terms were not significant in preliminary analyses (P = 0.05). Cumulative tree death averaged from 2.4% to 11.770 per year depending on the treatment combination (Fig. 1). The regression lines showed the largest and smallest coefficients (slopes) for sod under the trees. The slope of the regression line for sod with EDB (Trt. 1) was 4.9 times the slope of the line for sod without EDB (Trt. 6). We know of no logical reason why EDB should increase tree death if grass grew under the trees. For bare ground after planting, EDB either decreased cumulative tree death or had no effect. For bare ground without fenamiphos, the slope of the line with EDB was one-third of the slope without

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Table 4. Preplant fumigation, irrigation, postplant treatment, and year effects on elemental concentrations in peach leaves.

Variable	N	P	K	Ca	Mg	Mn	Fe	Al	B	Cu	Zn
	(g·kg⁻¹ dry wt)					(mg·kg⁻¹ dry wt)					
Preplant EDB fumigation (E)											
No	30.6 a[z]	1.9 a	20.2 a	12.1 a	4.3 a	42 a	65 a	72 a	35 a	4.7 a	17 a
Yes	29.9 a	1.9 a	23.0 a	12.9 a	4.4 a	39 a	70 a	79 a	36 a	4.7 a	17 a
Irrigation (I)											
No	31.0 a	1.9 a	21.7 a	12.4 a	4.4 a	42 a	68 a	73 a	34 b	4.7 a	18 a
Yes	29.5 b	1.9 a	21.5 a	12.5 a	4.4 a	40 a	66 a	78 a	37 a	4.7 a	17 a
Postplant treatment (P)											
Sod[y]	29.6 a	2.0 a	24.0 a	12.1 a	4.3 a	41 a	68 a	73 a	38 a	4.7 a	18 a
Bare	30.9 a	1.8 b	20.0 a	12.5 a	4.4 a	42 a	67 a	76 a	34 b	4.6 a	16 a
Bare +	30.3 a	1.9 ab	20.8 a	12.8 a	4.4 a	40 a	67 a	78 a	35 b	4.9 a	17 a
Year (Y)											
1985	37.5 a	2.4 a	24.9 a	15.0 a	4.6 a	53 a	87 a	95 a	46 a	6.6 a	25 a
1986	28.2 b	1.6 b	18.9 a	10.0 c	4.1 b	32 c	56 b	42 b	27 c	3.7 b	13 b
1987	24.8 c	1.7 b	20.9 a	12.5 b	4.4 ab	37 b	58 b	90 a	33 b	3.7 b	14 b
Significant interactions ($P = 0.05$)	P × Y	P × Y	---	P × Y	I × P × Y	---	P × Y E × Y	P × Y E × Y	I × Y	---	E × Y
r^2	0.76[x]	0.63	0.15	0.53	0.24	0.39	0.64	0.52	0.74	0.68	0.60
Sufficiency range for Georgia[w]	27.5	1.2	15.0	12.5	2.5	20	60	---	20	5	15
	35.0	5.0	25.0	25.0	5.0	150	400	<400	45	20	50

[z]Letters indicate significance at $P = 0.05$ with Tukey's test. Means of 56 observations for postplant treatment and 84 observations for other treatments.
[y]Sod, Bare, and Bare+ indicate bahiagrass sod, bare ground, and bare ground plus fenamiphos, respectively.
[x]Proportion of the total variability explained by the treatments and treatment combinations combined.
[w]Taken from Plank (1989a).

Table 5. EDB fumigation effects on element concentrations of peach leaves by year.

Year	Preplant EDB fumigation	Fe	Al	Zn
		(mg·kg⁻¹ dry wt)		
1985	No	84 a[z]	87 a	24 a
	Yes	91 b	102 b	26 b
1986	No	56 a	45 a	13 a
	Yes	56 a	39 a	13 a
1987	No	55 a	85 a	14 a
	Yes	63 b	96 a	13 a

[z]Means of 42 observations. Letters indicate significance at $P = 0.05$ between EDB treatments within a year by Tukey's test.

Table 6. Postplant treatment effects on element concentrations of peach leaves by year.

Year	Postplant treatment	N	P	Ca	Fe	Al
		(g·kg⁻¹ dry wt)			(mg·kg⁻¹ dry wt)	
1985	Sod[z]	37.5 a[y]	2.4 a	13.6 a	84 a	78 a
	Bare	37.4 a	2.3 a	15.4 b	88 a	101 b
	Bare +	37.8 a	2.4 a	15.9 b	90 a	104 b
1986	Sod	28.2 a	1.6 a	10.2 a	61 a	47 a
	Bare	28.4 a	1.6 a	9.8 a	53 a	40 a
	Bare +	28.0 a	1.6 a	9.9 a	53 a	41 a
1987	Sod	22.4 a	1.9 b	12.4 a	57 a	93 a
	Bare	26.7 b	1.6 a	12.4 a	59 a	88 a
	Bare +	25.0 b	1.6 a	12.6 a	59 a	89 a
Tukey's HSD ($P = 0.05$)		2.2	0.3	1.4	10	18

[z]Sod, Bare, and Bare + indicate bahiagrass sod, bare ground, and bare ground plus fenamiphos, respectively.
[y]Means of 28 observations.

EDB (Trts. 2 and 5). For bareground with fenamiphos, EDB had no effect on the slope of the lines (Trts. 3 and 4). Fenamiphos applications never gave a positive response; i.e., fewer dead trees. Fenamiphos on bare ground had no effect on the slope of the regression line when no EDB was used (Trts. 2 and 3), but fenamiphos applications increased the slope (Trts. 4 and 5). Based only on tree death, we would recommend either preplant EDB fumigation followed by bare ground or no EDB followed by sod.

Tree death and symptoms of PTSL occurred even though populations of *C. xenoplax* were almost nonexistent. More than *C.* xenoplax may be involved in PTSL at some old orchard sites. There was a weak relationship between the proportion of dead trees at the end of the experiment in 1988 and the population of *C. xenoplax* present in Ott. 1985; however, this relationship explained only 6.6% of the total variability in tree death. The low populations of *C. xenoplax* and the small amount of variability attributed to *C. xenoplax* makes it unlikely that there was a cause-and-effect relationship between C. *xenoplax* and tree death in this experiment. No pruning was done during September through December, so fall pruning did not cause tree death. No positive relationship was found between tree death and populations of root-knot nematodes. Additional research will be needed to identify the cause of tree death.

TCA was 36% larger for trees at sites with EDB than at sites without EDB, and TCA was 76% to 87% larger for trees in bare ground than in sod (Table 7). Irrigation had no effect on TCA, but the amount of water applied to the irrigated trees was not measured. Two emitters per tree usually provide sufficient water for good growth in the southeastern United States (Harrison, 1989), and two emitters per tree with a switching-ten-

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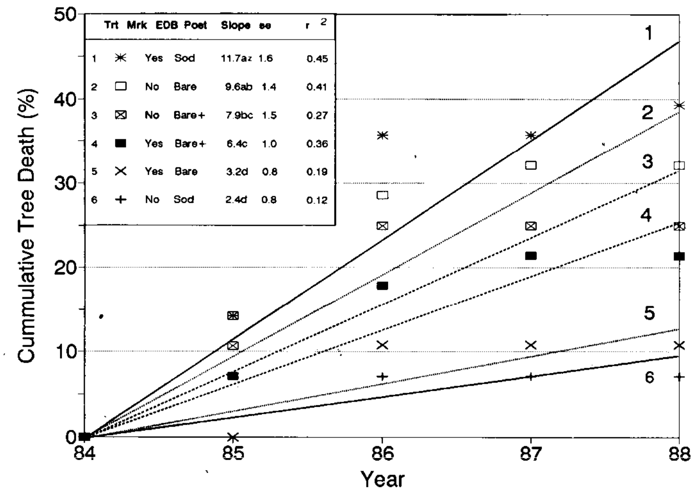

Fig. 1. Cumulative peach tree death by year in response to preplant EDB fumigation and postplant treatments of bahiagrass sod, bare ground, and bare ground plus fenamiphos. A common intercept was calculated for all regression lines because all trees were alive in 1984.

ʻLetters indicate differences among the slopes ($P = 0.05$, t test). Each number represents the mean of 28 observations.

Table 7. Preplant fumigation, irrigation, postplant treatment, and year effects on TCA of live peach trees.

Treatment	TCA (cm^2)	No. observations
Preplant EDB fumigation (E)		
No	13.0 b[z]	358
Yes	17.7 a	357
Irrigation (I)		
No	15.0 a	357
Yes	15.4 a	358
Postplant treatment[y] (P)		
Sod	10.2 b	237
Bare	18.0 a	241
Bare +	19.1 a	237
Year (Y)		
1984	0.7 e	168
1985	3.4 d	153
1986	53.9 c	133
1987	69.4 b	131
1988	89.6 a	130

[z]Letters within a column and treatment indicate significance at P = 0.001 indifferent, P > 0.2 if same (Tukey's test). Trunk areas were log-transformed to stabilize the variance and back-transformed for presentation. All treatment interactions were nonsignificant.

[y]Sod, Bare, and Bare+ indicates bahiagrass sod, bare ground, and bare ground plus fenamiphos, respectively.

siometer in bare ground under a tree produced good tree growth in a previous orchard at this site. The lack of response to supplemental irrigation, regardless of the presence of sod under the trees, probably means that soil moisture was not a limiting factor during this experiment. Fenamiphos applications failed to increase TCA. This result is consistent with the general lack of positive responses to fenamiphos applications in this experiment.

Yield of fruit. Trees in soil fumigated with EDB yielded 12.6 kg in once-over harvest in 1987. This yield was higher than the 9.7-kg yield of trees in nonfumigated soil ($0.05 < P < 0.1$). Trees in bahiagrass sod yielded 5.8 kg, which was much lower than the yield of trees in bare ground with fenamiphos (13.6 kg) or without fenamiphos (14.1 kg) (LSD = 4.1; $P = 0.01$). Yield was independent of irrigation. The increased yield associated with EDB and with bare ground is a reflection of increased TCA for sites fumigated with EDB and free of bahiagrass.

Yield (kilograms per tree) in 1987 was linearly related to TCA (cm') in Fall 1986 by the formula: yield = –0.72 + 0.20 × area. The intercept (– 0.72) in the yield equation was not significant ($P > 0.5$), but the slope (0.20) was ($P < 0.0001$). Addition of a quadratic term to the regression equation did not improve the fit. The equation explained 29% of the variation in yield. These results are consistent with those of Welker and Glenn (1989), who found that peach yield increased as TCA increased.

Fruit weight was independent of irrigation (data not shown). Fruit weight varied for combinations of postplant treatment and preplant fumigation. Fruit averaged 73 g for EDB fumigation followed by bare ground without fenamiphos, 65 g for EDB fumigation followed by bare ground with fenamiphos, and 51 g for EDB fumigation followed by sod (LSD = 17; $P = 0.05$). Although significant, the small fruit on the trees in sod probably reflects the difficulty in thinning small and large trees to the same relative crop load. Fruit from plots without EDB fumigation weighed from 59 to 68 g, and these weights were independent of postplant treatment ($P > 0.2$).

Growth vs. nutrition. Stepwise regression was used to examine the relationship between TCA and leaf element concentrations. In this procedure, the most significant element concentration not in the model was added to the model. All element concentrations in the model then were examined and those that were no longer significant were removed from the model. This procedure continued until all elements that were significant were included in the model and all elements that were nonsignificant were eliminated (SAS Institute, 1985).

TCA in 1987 was related to leaf concentrations of the eight elements in the following equation: $\log_{10}(Area_{87}) = 1.87 - 0.62(P_{87}/1.7 - 1) - 0.44(Mg_{86}/4.1 - 1) - 0.47(Zn_{87}/13 - 1) + 0.42(N_{87}/24.8 - 1) - 0.42(N_{85}/37.5 - 1) + 0.42(Cu_{87}/4 - 1) + 0.27(Ca_{85}/15 - 1)$. The coefficient of each element in the equation was significant at $P < 0.01$; no other elements were significant at $P = 0.05$. The stepwise regression equation explained 65% of the total variability in trunk area ($P = 0.0001$). Subscripts of the elements in the equation show the year of measurement, and denominators are the mean concentrations of the elements that year. Zinc and Cu concentrations are in milligrams per kilogram and the other elements are in grams per kilogram. The coefficient of each element shows the relative sensitivity of the TCA to variations in concentrations of that element. The equation suggests that TCA was most sensitive to the concentration of P. The corresponding regression equations for 1986 and 1988 explained 40% and 43%, respectively, of the variability in TCA ($P = 0.0001$) (data not shown). Significant elements in the 1986 regression equation were Ca_{85}, Cu_{85}, Fe_{86}, N_{85}, and Mg_{85}; significant elements in the 1988 regression equation were Ca_{85}, Mg_{85}, Mg_{86}, and P_{87}.

Negative coefficients in the equation imply that tree growth would decrease if the concentration of that element were increased relative to its average concentration. Similarly, positive coefficients imply that tree growth would increase if the concentration of that element were increased relative to its average " concentration. Thus, negative coefficients can be interpreted as

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elements present at concentrations too high for best tree growth, and positive coefficients as elements present at concentrations too low.

The negative coefficient for N_{85} in the regression equation for trunk area in 1987 indicated that less N fertilizer should have been applied in 1985. Leaf N in 1985 was above the recommended range (Table 4). The positive coefficient for N_{87} in the equation indicates additional N fertilizer was needed; leaf N in 1987 was below the sufficiency range (Table 4). The supplemental applications of 44.8 kg N/ha in 1986 and 28.7 kg N/ha in 1987 were inadequate to maintain leaf N in the sufficiency range for Georgia. Leaf N was equivalent for trees in sod and bare ground in 1985 and 1986 (Table 6). Only in 1987 was leaf N lower for trees in sod than in bare ground.

The large negative coefficient for leaf P_{87} in the regression equation was unexpected. The coefficient for leaf P_{87} in the regression equation ‘for 1988 was also negative (data not shown). Reduced yield has been reported when high rates of P were combined with low rates of N (Ritter, 1988). Weller et al. (1985) reported that leaf P increased the year after planting as the density of common bermudagrass under the peach trees increased.

The stepwise regression analysis cannot establish a cause-and-effect relationship between concentration of leaf P and TCA. However, our research, like that of Weller et al. (1985), indicated that grasses increased leaf P under peach trees relative to bare ground. Additional research will be needed to determine if the recommended sufficiency ranges for leaf elements need to be modified when grasses are grown in. the orchard.

The effects of leaf Mg and Ca were considered together because of an apparent competitive relationship between these two elements. The equation relating TCA in 1987 and leaf Mg concentration in 1986 had a negative coefficient for MG, showing that leaf Mg in 1986 was too high for the best tree growth in 1986 and 1987. Similar results occurred for the equations relating TCA in 1986 and 1988 and leaf Mg concentrations in 1985 or 1986 (data not shown). Concentrations of leaf Mg were in the sufficiency range for Georgia throughout the experiment (Table 4). The same equations that showed a negative relationship between leaf Mg concentration and TCA showed positive relationships between TCA in 1986, 1987, and 1988 and leaf Ca in 1985. The positive coefficient for Ca in the regression equations are consistent with the low Ca in the leaves (Table 4). Low leaf Ca occurred in spite of near neutral soil pH and soil Ca levels (Table 3) that were well above the soil deficiency level of 225 $kg \cdot ha^{-1}$ for Georgia (Plank, 1989b). Low leaf Ca concentrations occurred in all trees whether in bahiagrass sod or bare ground (Table 6); therefore, the stunting associated with bahiagrass probably was not a result of Ca deficiency.

The near neutral soil pH measured in this experiment is consistent with the report by Hogue and Neilsen (1987) that orchards in sod tend to maintain a near neutral pH. Beaty and Tan (1972) reported that bahiagrass sod had twice the organic matter, and with this grass, bases accumulated nearer the soil surface than in a fallow soil. Perhaps the increased organic matter binds Ca and makes it unavailable to the tree; however, the trees had no visual symptoms of Ca deficiency.

In summary, the severe stunting of the peach trees demonstrates that bahiagrass should not be allowed to grow directly under newly planted trees. The relationship between tree growth and leaf element concentrations, the near neutral soil pH, low leaf Ca, and the lack of response to drip irrigation all show the need for further research on the effects of bahiagrass on peach trees. The reduced nematode populations in the bahiagrass sod indicates that bahiagrass grown at an orchard site for a year or so before replanting the site may have potential as a biological control of nematodes harmful to peach trees.

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