Effects of Dazomet, Metam Sodium, and Oxamyl on *Longidorus* Populations and Loblolly Pine Seedling Production

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ABSTRACT: *Dazomet, metam sodium, and oxamyl were evaluated for nematode control and production of loblolly pine seedlings in a field infested by a* Longidorus *sp. Fumigation with dazomet or metam sodium reduced population densities of* Longidorus *to nondetectable levels early in the growing season but population densities subsequently increased to levels found in untreated control plots by the end of the growing season. Oxamyl had no effect on* Longidorus *population densities. Seedlings in dazomet-treated plots had significantly greater root and shoot weights than seedlings in control and oxamyl-treated plots within 6 weeks of seed sowing. At the end of the growing season, seedlings in the control and oxamyl plots were very stunted with poorly developed root systems. Seedling shoot length and root collar diameter in dazomet-treated plots averaged 27.4 cm and 4.0 mm, respectively, but in nonfumigated control plots these variables averaged 10.5 and 2.5 mm, respectively. Although dazomet and metam sodium were effective in reducing* Longidorus *populations for the first seedling crop after fumigation, production of a second crop without additional treatment would be inadvisable based on the increased population of* Longidorus *by the end of the first growing season. South. J. Appl. For. 29(3):117–122.*

Key Words: Disease, forest-tree nursery, nematode, pest management.

Areas of stunted and chlorotic loblolly pine (*Pinus taeda* L.) seedlings have been periodically observed at the Flint River Nursery (Byromville, GA), and an undescribed *Longidorus* sp. was associated with the problem. The *Longidorus* sp. reproduces on pine roots and causes major damage to root systems of loblolly pine (Fraedrich and Cram 2002, Fraedrich et al. 2003). The number of lateral and feeder roots are greatly reduced, resulting in seedlings that are severely stunted. When initially observed, damage is usually confined to isolated, small patches of seedlings that are 3–9 m in length and one seedbed wide (Fraedrich and Cram 2002). However, damage was more widespread in a section of one field in 2001, with areas of damage up to 60 m in length and occurring across multiple seedbeds. The *Longidorus* sp. was recently described and named *Longidorus americanum* n. sp. (Handoo et al. in press).

Fumigation with methyl bromide has been routinely used in southern forest-tree nurseries for more than 40 years and is regarded as a reliable practice for controlling weeds, soilborne pathogenic fungi, insects, and plant-parasitic nematodes. Methyl bromide has been identified as an ozone-depleting chemical, and a phaseout of its production is scheduled to begin in 2005 in accordance with the United States Clean Air Act and the Montreal Protocol (Environmental Protection Agency 1999), although exemptions are being proposed on a yearly basis for some crops, including forest-tree seedlings (Environmental Protection Agency 2004). Other soil fumigants are available, but information is lacking on their efficacy to control various pest problems. Dazomet and metam sodium are fumigants that have provided control of some soilborne pathogenic fungi and plant-parasitic nematodes in forest-tree nurseries (Barnard et al. 1994, Hildebrand and Dinkel 1988). Oxamyl, a carbamate nematicide, can also reduce *Longidorus* population densities and increase crop yield in fields affected by these plant-parasitic nematodes (Jatala and Jensen 1974, Pinkerton and Jensen 1983). Therefore, this nematicide has potential benefits as a

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presowing soil treatment in forest-tree nurseries where *L. americanum* or other plant-parasitic nematodes are problems.

Information about specific pest problems and effective strategies for their control are necessary to develop integrated pest management programs for southern forest-tree nurseries in the future. The specific objectives of this study were to evaluate the effects of dazomet, metam sodium, and oxamyl on: (1) population densities of *L. americanum* and (2) seedbed densities and quality of loblolly pine seedlings.

Materials and Methods

Study Location and Design

The study was conducted in a section of a field at the Flint River Nursery (Byromville, GA) where the *L. americanum* was established and had caused severe losses of loblolly pine seedlings. The study area (73 m long and 9.8 m wide) was located between two riser lines. The soil at the nursery was a loamy sand (86% sand, 9% silt, 5% clay, pH 5.6, 1.8% organic matter) and classified in the Eustis soil series. The experimental design was a randomized complete block consisting of four treatments and four blocks. Study plots were 9.1 m long and 4.9 m (three seedbeds) wide. Treatments were applied on Mar. 27 and 28, 2002, and consisted of dazomet applied at 560 kg/ha, metam sodium at 360 kg a.i./ha, oxamyl at 4.5 kg a.i./ha, and a nontreated control. Metam sodium and oxamyl were sprayed on the soil surface of plots, incorporated immediately with a Bushhog rototiller to 15–20 cm depth, and then covered with plastic tarps. Dazomet was applied to plots with a Gandy drop spreader, incorporated with a rototiller to 15–20 cm depth, irrigated with 2.5 cm of water from overhead irrigation, and covered with plastic tarps. Soil temperatures ranged from 12° C at 09:00 to 22° C at 14:00 at a 10-cm depth during pesticide applications. Tarps were removed after 8 days, plots were rototilled, and chemicals were permitted to dissipate for 12 days before seed sowing. Loblolly pine seeds were operationally sown on Apr. 17, 2002. All cultural practices, including fertilization and watering, were applied operationally and uniformly to all treatment plots. Soil and seedling samples were collected from the center bed of each plot; beds to either side of center and 3 m on each end of the center beds served as treatment buffer areas.

Longidorus Assessments

Population densities of *L. americanum* were determined from soil samples obtained 1 day prior to application of treatments, 14 days after the application of treatments, 12 days after seed sowing, and then at 2- to 12-week intervals through Nov. 2002. Soil samples were a composite of eight soil cores (2.5 cm diameter, 15 cm depth) per plot. Samples were thoroughly mixed and *Longidorus* were extracted using the procedure of Flegg (1967) with modifications by Fraedrich and Cram (2002).

Seedling Density and Morphological Characteristics

Three permanent sample plots (0.3 × 0.6 m) were established in each treatment plot immediately after seed sowing to evaluate bed densities. Live and dead seedlings were counted in sample plots on May 14 and Nov. 6, 2002.

Seedling morphological characteristics were evaluated on May 28, July 1, Sept. 4, and Nov. 6, 2002. At each date, approximately 15–20 seedlings were lifted at each of three locations within treatment plots (45–60 seedlings/treatment plot). Samples were obtained near the plot centers and approximately 3 m to either side of center. The number of root tips and total root lengths were determined in May, July, and Nov. on 15 seedlings per treatment plot (five from each sample location) with an EPSON STD1600+ Transparency Scanner and WINRHIZO (Regent Instrument Company, Canada). Shoot and root weights were determined for 30 seedlings per treatment plot (10 seedlings/sample location) on all sample dates. Roots and shoots were separated at the root collar and dried at 80°C for 48 h prior to weighing. Seedling shoot lengths were determined for 30 seedlings/treatment plot (10 seedlings/sample location) in July, Sept., and Nov. by measuring from the root collar to the shoot tip. Seedling root collar diameters were determined in Nov. on seedlings used for shoot length determinations.

Data Analysis

Statistical comparisons of treatments for all variables were conducted by an analysis of variance (ANOVA) using PROC GLM in SAS (The SAS System for Windows, Version 8.01; SAS Institute, Inc., Cary, NC). Tukey's HSD test was used for mean separation when treatment effects within an ANOVA were significant. *Longidorus* population densities and counts of dead seedlings were transformed with a square root transformation prior to analysis to correct for heterogeneity of variance (Steel and Torrie 1980). Differences among treatment means were determined at the $P = 0.05$ level.

Results

Longidorus Population Densities

Prior to the application of treatments, mean population densities of *L. americanum* ranged from 27 to 47 nematodes/100 cm^3 soil among plots allocated for specific treatments (Figure 1), and there were no significant differences among treatment means ($P = 0.1317$). During posttreatment assessments on Apr. 11, *L. americanum* was not detected in metam sodium- or dazomet-treated plots, but oxamyl had no significant effect on *Longidorus* population densities. *Longidorus americanum* began to colonize the upper 15 cm of soil treated with dazomet and metam sodium after seed sowing, resulting in mean population densities of 1.5–5 nematodes/100 cm^3 soil in these treatments on May 14. By June 10, only the dazomet treatment had significantly lower nematode population densities compared to the control, and no significant differences were observed among treatments at the final assessment in Nov. 2002 ($P = 0.2879$).

Seedling Density and Morphological Characteristics

Densities of live and dead seedlings in seedbeds did not differ among treatments on May 14, but on Nov. 6 the

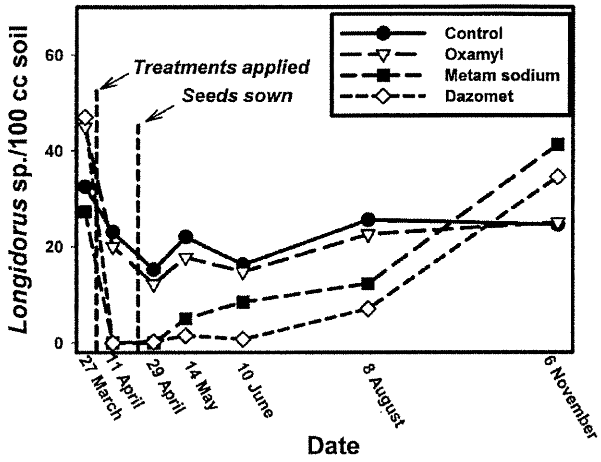

Figure 1. Mean population density of *L. americanum* in dazomet, metam sodium, oxamyl, and control plots prior to the application of treatments, 14 days after the application of treatments, and at selected dates in a field with loblolly pine seedlings during 2002.

number of live seedlings/0.093 m^2 was significantly greater in the dazomet treatment compared to all other treatments (Table 1). Some seedling mortality was observed in the control and oxamyl-treated plots during evaluations on Nov. 6, but mortality was not observed in beds treated with metam sodium or dazomet.

Seedlings in control and oxamyl plots were often stunted with poorly developed root systems throughout the growing season. Differences in seedling morphological characteristics were evident between the dazomet and control treatments within 6 weeks of seed sowing, and differences generally continued through to the final sample date in Nov. (Table 2). Seedlings had significantly fewer root tips and smaller total root lengths in the control than the dazomet-treatment plots during May, July, and Nov. evaluations. The number of root tips and total root lengths were greater in the metam sodium treatment than the control for most sample dates, and these variables frequently did not differ between metam sodium and dazomet. Shoot dry weights were consistently lower in the control and oxamyl plots compared to dazomet plots throughout the growing season. Root dry weights were also significantly less in the control and oxamyl treatments compared to the dazomet treatment at most sample dates although no differences were detected among treatments at the Nov. evaluation. Shoot lengths were greater in the dazomet-treated plots than the control or oxamyl-treated plots within 75 days of seed sowing, and these differences continued through the growing season. Seedling root collar diameters differed significantly (P = 0.0021) among treatments on Nov. 6. The mean seedling root collar diameters in the dazomet and metam sodium treatments were 4.0 and 3.7 mm, respectively, and differed significantly from root collar diameters in oxamyl-treated (2.6 mm) and control plots (2.5 mm). Seedling root collar diameters did not differ significantly between the dazomet and metam sodium treatments.

Discussion

Soil fumigation with dazomet or metam sodium reduced *L. americanum* to nondetectable levels in the upper 15 cm of soil early in the growing season and greatly increased the size of loblolly pine seedlings compared to seedlings in the control plots. Despite the dramatic reductions of *Longidorus* population densities in fumigated plots, the nematode reestablished gradually during the growing season in the upper soil layer, and by the final evaluation in Nov., population densities had increased in dazomet and metam sodium plots to levels found in control plots. Growth and yield of annual crops is primarily a function of preplant densities of plant-parasitic nematodes (Barker and Olthof 1976). The age of plants when first attacked by nematodes can also be a factor in the amount of damage that plants sustain (Huang and Ploeg 2001, Ploeg and Phillips 2001, Wong and Mai 1973). For instance, Huang and Ploeg (2001) found that a delay of just 10 days between sowing seeds and inoculation with nematodes could greatly increase the minimum yield of lettuce plants. Similarly, the action of the fumigants in the present study permitted loblolly pine seedlings to become

Table 1. Seedbed densities of live and dead loblolly pine seedlings by treatment on two sample dates at a south Georgia forest-tree nursery during 2002.

		Seedlings/0.093 m^2	
Date	Treatment	Live	Dead
May 14	Control	20.0 a*	0.20 a
	Oxamyl	19.8 a	0.04 a
	Metam sodium	20.4 a	0.04 a
	Dazomet	21.3 a	0.17 a
	P value[a]	0.7052	0.6711
	TMSD[b]	4.11	–
Nov. 6	Control	18.4 a	0.79 a
	Oxamyl	18.6 a	0.21 a
	Metam sodium	19.4 a	0.00 a
	Dazomet	21.4 b	0.00 a
	P value	0.0022	0.0884
	TMSD	1.82	–

* Means within sample date followed by the same letter are not significantly different ($P \leq 0.05$) among treatments according to Tukey's HSD procedure.
[a] *P* value for treatment effects in the ANOVA.
[b] TMSD, Tukey's Minimum Significant Difference.

Table 2. Mean number of root tips, total root length, root and shoot dry weight, and shoot length among treatments for loblolly pine seedlings at evaluation dates. The study was conducted at a south Georgia forest-tree nursery during 2002.

Date (Month/day)	Treatment	Root tips (number)	Total root length (cm)	Root dry wt. (g)	Shoot dry wt. (g)	Shoot length (cm)
May 28	Control	26 a*	13 a	0.0092 a	0.0380 a	–
	Oxamyl	31 ab	16 ab	0.0101 ab	0.0380 a	–
	Metam sodium	64 bc	32 bc	0.0138 bc	0.0461 b	–
	Dazomet	78 c	41 c	0.0158 c	0.0582 c	–
	P value[a]	0.0040	0.0012	0.0047	<0.0001	–
	TMSD[b]	36.8	16.1	0.0046	0.0070	–
July 1	Control	34 a	20 a	0.0252 a	0.1060 a	4.6 a
	Oxamyl	52 ab	29 ab	0.0341 a	0.1202 a	5.1 a
	Metam sodium	94 ab	54 bc	0.0381 ab	0.1800 a	7.2 ab
	Dazomet	110 b	68 c	0.0510 b	0.2823 b	10.2 b
	P value	0.0296	0.0036	0.0060	0.0003	0.0013
	TMSD	71.8	31.4	0.0165	0.0803	3.126
Nov. 4	Control	–	–	0.1636 a	0.6085 a	9.9 a
	Oxamyl	–	–	0.1787 a	0.7599 a	11.6 a
	Metam sodium	–	–	0.2225 ab	1.2247 a	18.2 b
	Dazomet	–	–	0.2929 b	2.2114 b	26.8 c
	P value	–	–	0.0085	0.0002	<0.0001
	TMSD	–	–	0.0942	0.7054	6.393
Nov. 6	Control	73 a	71 a	0.3606 a	0.8472 a	10.5 a
	Oxamyl	97 ab	84 ab	0.3580 a	0.9908 a	12.5 a
	Metam sodium	184 bc	155 bc	0.5226 a	2.3866 b	22.3 b
	Dazomet	216 c	182 c	0.5215 a	2.7890 b	27.4 b
	P value	0.0018	0.0045	0.0847	0.0009	0.0003
	TMSD	87.7	79.0	0.2375	1.1493	8.0

* Means within sample date followed by the same letter are not significantly different ($P \le 0.05$) among treatment according to Tukey's HSD test.
[a] *P* value for treatment effects in the ANOVA.
[b] TMSD, Tukey's Minimum Significant Difference.

well established before roots were attacked by *L. americanum.* Pine seedlings were more than 3 months of age before the population density of the nematode increased in dazomet-treated plots to a level comparable to that found in control plots.

Nematodes can survive in areas where fumigants fail to penetrate, or below the zone of fumigant placement, and nematode population densities often increase greatly following the use of fumigants and nematicides (Sipes and Schmidt 1998). *Longidorus* spp. have been documented at soil depths greater than 60 cm (Ploeg 1998, Flegg 1968), and they can migrate vertically through soil (MacGuidwin 1989, Rossner 1991). Although fumigation with dazomet and metam sodium reduced *Longidorus* to nondetectable levels early in the growing season in this study, some nematodes probably survived below the fumigation zone. Individuals that survived fumigation most likely immigrated into the fumigated soil zone during the late spring and summer, and the population increased rapidly on the well-developed root systems of the established pine seedlings.

Population densities of plant-parasitic nematodes can also decline in fields where they have caused severe damage to root systems of smaller plants (Barker and Olthof 1976). Although *Longidorus* population densities did not decline in control and oxamyl-treated plots, their populations remained somewhat static throughout the growing season. The lack of increase in population densities was probably directly related to the limited growth and smaller size of root systems found in these treatments. The smaller size of the root systems provided fewer sites for nematode feeding and thus reduced the potential for reproduction.

Metam sodium generally performed well in this study; however, one plot had noticeably smaller seedlings than others of this treatment throughout the growing season. At the final assessments in Nov., the average root collar diameter of seedlings in the affected plot was 2.7 mm and their shoot length was 12.7 cm, but in other metam sodium-treated plots the root collar diameters ranged from 3.7 to 4.2 mm, and shoot lengths ranged from 24.9 to 26.7 cm. Population densities of *L. americanum* were 11 and 31 nematodes/100 cm^3 soil on the affected plot on May 14 and Aug. 8, respectively, but on the other metam sodium-treated plots, densities ranged from 2 to 4 nematodes/100 cm^3 soil in May, and 2 to 9 nematodes/100 cm^3 soil in Aug. We are uncertain of the reason for the accelerated recolonization of the *L. americanum* on the one metam sodium-treated plot, but the problem was most likely due to pesticide application error or contamination of the treated seedbed with infested soil rather than a deficiency in the performance of the chemical.

Seedling mortality was not observed in the dazomet- and metam sodium-treated plots during evaluations at the end of the growing season in Nov. Mortality observed in control and oxamyl treated-plots was probably the result of poorly developed root systems and irrigation practices. Prior to lifting seedlings operationally, the frequency of irrigation is reduced at the nursery to slow seedling growth. Periods of low rainfall during the late summer and fall of 2002 probably also contributed greatly to the mortality of seedlings with poorly developed root systems.

Oxamyl had negligible effects on the *Longidorus* population density and seedling quality in the present study. The lack of response may have been due, in part, to the our rate of application, and possibly application procedures. LaMondia (1990) found that oxamyl reduced root infection by *Globodera tabacum* when applied at 6.7 kg a.i./ha and incorporated to a 10-cm depth. In the present study, we used a rate of only 4.5 kg a.i./ha, and oxamyl was incorporated to a 15- to 20-cm depth. However, results of studies with oxamyl have been generally variable. Oxamyl, applied to soil or to foliage of crops, has been effective to varying degrees for control of plant-parasitic nematodes and increasing plant growth and yield (Willis and Thompson 1973, Miller 1971, Pinkerton and Jensen 1983). Soil-incorporated oxamyl has provided worthwhile increases in yield of sugar beet in fields affected by Docking disorder caused by species of *Trichodorus* and *Longidorus* (Cooke 1989). In other studies, however, the benefits of oxamyl have been negative. For example, in contrast to results by Cooke (1989), oxamyl applications failed to significantly increase sugar production in sugar beet fields affected by Docking disorder (Maughan et al. 1984), and, in another study, population densities of *L. elongatus* did not decrease in field soil treated with oxamyl at rates as great as 22.4 kg a.i./ha (Forer et al. 1975).

The impact of increasing *Longidorus* population densities in the dazomet-treated plots during the summer and fall had no noticeable effect on seedling quality. Based on measurements of shoot length and root collar diameter, the growth of loblolly pine seedlings in the dazomet-treated plots was comparable to that previously reported in fields at the Flint River Nursery where nematodes were not a problem (Carey 2000, Fraedrich and Dwinell 2003a, 2003b). Loblolly pine seedlings can sustain some damage to root systems without a loss in quality once they are well established in nursery beds. At many southern nurseries root systems of pine seedlings are operationally undercut from Aug. to Oct. to restrict root growth (May 1984). Therefore, *Longidorus* feeding on the established pine seedlings later in the growing season probably did not adversely affect seedling quality.

The objective of soil fumigation, as with other pest control strategies, is not pest eradication but rather the reduction of pest populations (Lembright 1990). The magnitude of the reductions must be sufficiently great so that population densities are not able to rebuild to levels that would adversely affect production and quality (Lembright 1990). Fumigation performed well in the present study for the production of pine seedlings over a 1-year production cycle. However, due to the reestablishment of *L. americanum* in fumigated plots at levels comparable to those found in control plots it is doubtful if a second pine crop could be produced without additional control measures. Many southern nurseries, including the Flint River Nursery, typically produce two consecutive pine crops in fields following fumigation with methyl bromide (Cram and Fraedrich 1996), and fields are then rotated to cover crops for 2 years. Other nurseries prefer other sequences such as yearly rotations of pine seedlings with cover crops (Boyer and South 1984, Cram and Fraedrich 1996). The field in which *L. americanum* has caused problems has not been part of a normal crop rotation sequence used in forest-tree nurseries and was in continuous production for pine and oak seedlings since 1990 (Cram et al. 2003). Operational fumigation of the field has not been effective for elimination of the nematode or the damage that it causes (Cram et al. 2003). Seedling damage and stunting caused by *Longidorus* has recurred during the second year following fumigation in this field (Cram et al. 2003). Similarly, fumigation with dazomet and metam sodium were effective in the present study for temporarily reducing *Longidorus* population densities and producing a single crop of seedlings before populations of the nematode rebounded. Because fumigation provides only 1 year of control, rotation to nonhost cover crops (Fraedrich et al. 2003), and periods of fallow (Cram and Fraedrich 2003) should also be considered as part of a program for management of this nematode.

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