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Efficacy of 1,3-Dichloropropene in Soil Amended with Compost and Unamended Soil[1]

C. Riegel,[2] S. D. Nelson,[3] D. W. Dickson,[2] L. H. Allen, Jr.,[3] and L. G. Peterson[4]

Abstract: 1,3-Dichloropropene (1,3-D) is a likely alternative soil fumigant for methyl bromide. The objective was to determine root-knot nematode, *Meloidogyne incognita*, survival in microplots after exposure to 1,3-D for various periods of time in soil that have previously been amended with compost. The treatments were 1,3-D applied broadcast at 112 liters/ha and untreated controls in both compost-amended and unamended soil. Soil samples were collected from each microplot at 6, 24, 48, 72, and 96 hours after fumigation at three depths (0–15, 15–30, and 30–45 cm). One week after fumigation, six tomato seedlings were transplanted into each microplot and root galling was recorded 6 weeks later. Plants grown in fumigated compost-amended soil had more galls than plants from fumigated unamended soil at $P \leq 0.1$. Gall indices from roots in fumigated soil amended with compost were not different from nonfumigated controls. Based on soil bioassays, the number of galls decreased with increasing time after fumigation in both compost-amended and unamended soil at 0-to-15 and 15-to-30 cm depths, but not at 30 to 45 cm deep. Higher soil water content due to the elevated levels of organic matter in the soil at these depths may have interfered with 1,3-D movement, thus reducing its efficacy.

Key words: compost-amended soil, deep sand soil, 1,3-dichloropropene, fumigation, *Lycopersicon esculentum, Meloidogyne incognita*, nematicide, nematode, root-knot nematode, tomato.

The phase-out of methyl bromide in 2005 will require alternative chemicals that provide similar levels of control for soilborne pests and pathogens of high-value vegetable crops, plant beds for seedling production, some ornamentals, and turfgrass renovations or new installations. 1,3-Dichloropropene (1,3-D) formulated with chloropicrin provides a broad spectrum of activity for the management of nematodes and soilborne plant pathogens (Fletcher, 1956; Youngson and Goring, 1970) and is considered the likely replacement for methyl bromide. Although this compound has been used successfully to manage plant-parasitic nematodes on many important agricultural crops (Dickson, 1985; Lembright, 1990; Sipes et al., 1993), there are instances where management of nematodes with 1,3-D may not meet expectations. For example, there are instances where efficacy of 1,3-D is affected negatively by concentration and length of exposure (Youngson and Goring, 1962), temperature, soil type and moisture, nematode species, and stage of nematode development. Organic matter, soil compaction, and tilth are other factors that may affect the dispersion of soil fumigants (Thomason and McKenry, 1974). The recycling of urban solid waste has increased in recent years as cities strive to reduce their use of limited landfill space. In some cities, yard waste is no longer allowed to be placed in landfills (Kaar, 1991). In California, yard and landscape green wastes represent approximately 25% of the solid waste produced, so composting green wastes has become commonplace (Hartz and Giannini, 1998). Composting yard waste and selling it for agricultural use is being promoted as a method for disposal. Addition of compost to agricultural land has been shown to enhance soil structure, increase soil fertility, and suppress some plant diseases (Hoitink et al., 1993; Logsdon, 1993). While many growers add compost to the land to increase fertility and enhance soil structure, its addition for plant disease management often requires high application rates (e.g., 40 tons/ha for control of *Phytophthora* rot of soybean, Logsdon, 1993). The addition of these large quantities of organic matter to agricultural fields may impact other pathogen management tactics, such as soil fumigation. The objective of this study was to determine the efficacy of 1,3-D on root-knot nematodes after various exposure periods in compost-amended and unamended soil.

Materials and Methods

Microplots located at the Irrigation Research and Education Park at the University of Florida, Gainesville, were prepared in 1995 for other experiments (Sotomayor et al., 1999). The partially-buried microplots were 0.75 m^3 polyethylene stock watering tanks with a bottom and a surface area of 1.1 m^2 (Sotomayor et al., 1999). The bottom of each tank had a 5-cm-deep gravel layer underlain by a slit perforated pipe connected to a port for drainage. The soil added to the microplots was topsoil of an Arredondo fine sand with 94.8% sand, 2.4% silt, 2.8% clay (loamy, siliceous hypothermic Grossarenic Paleudult).

To prepare the compost-amended plots, soil was covered with a 10-cm depth of yard-waste compost, screened through a 1.3-mm × 1.3-cm wire screen, and incorporated with a shovel into the top 20 cm of soil on 21–23 August 1995. Yard-waste compost obtained from

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[2] Graduate student and Professor, Entomology and Nematology Department, Institute of Food and Agricultural Sciences, University of Florida. Gainesville, FL 32611-0620.
[3] Soil Scientist USDA ARS and Soil Scientist USDA ARS and courtesy professor, respectively, Agronomy Department, P.O. Box 110965, University of Florida, Gainesville, FL 32611-0965.
[4] Dow AgroSciences LLC, Technology Development, Tallahassee, FL 32308.
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E-mail: dwd@ufl.edu
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Enviro-Comp Service (Jacksonville, FL) was added at a rate of ca. 500 t (m)/ha. The microplots then were infested with *Meloidogyne incognita* (Kofoid and White) Chitwood race 1. Following experiments by Sotomayor et al. (1999) in 1996 and 1997, the nematode population was increased on hairy vetch (*Vicia villosa* Roth) during the winter and on tomato (*Lycopersicon esculentum* Mill.) during the spring and summer of 1998. Tomato seedlings cv. Solarset were transplanted in the spring of 1999 in all microplots before initiating the two trials. Stems of the tomato plants were cut at the soil line and the nematode galled roots were tilled under using a shovel on 24 June 1999 (trial 1) and 6 July 1999 (trial 2).

1,3-Dichloropropene was applied broadcast at a rate of 112 liters/ha injected with a glass syringe outfitted with a 30-cm-long, stainless steel needle to both compost-amended and unamended soil 13 July 1999 (trial 1) and 12 August 1999 (trial 2). Untreated microplots of both soils were included in the study as controls. A template was placed on the top of each microplot to accurately position the injection points 30 cm apart and 30 cm deep so that the entire subsurface layer was fumigated. The soil around the injection points was pressed firmly with a wooden stake, and 2 liters of water was sprinkled over the surface of each microplot to form a water barrier seal, which has been shown effective in reducing volatilization losses in the field (Gan et al., 1998). Soil moisture at the time of fumigation in trials 1 and 2 was determined. The average soil temperature 10 cm deep was 29.5 °C in trial 1 and 31 °C in trial 2. The experimental design was a randomized complete block with four replicates for both trials.

Each microplot was sampled 24 hours before fumigation and 6, 24, 48, 72, and 96 hours after fumigation. Six soil cores were taken at 0-to-15, 15-to-30, and 30-to-45-cm depths from each microplot with a soil sampling tube (2.5-cm-diam.). The six soil samples from each depth within each microplot were combined in a 10 × 15 × 20-cm, 0.002-cm thick polyethylene bag and taken immediately to the greenhouse for processing. The soil from each sample was shaken vigorously in the sample bag and aerated by opening the bag within 2 hours of sampling to allow dissipation of 1,3-D from the soil to minimize any further exposure of the second-state juveniles (J2) to the fumigant. The soil samples were transferred to 164-ml ultraviolet-stabilized conetainers (Stewe and Sons, Corvallis, OR) to bioassay the number of infective J2 that survived exposure to 1,3-D. Each bioassay was prepared on the same day of sampling. For each trial, 3-week-old 'Solarset' or 'Rutgers' (equally susceptible) tomato seedlings were transplanted into each conetainer. Since a single root system was in each conetainer, it was possible to count the number of galls per root system 6 weeks after transplanting as an indication of the number of infective J2 present.

Glyphosate was applied broadcast over all microplots at the labeled rate 1 week before fumigation for control of weeds. Six tomato seedlings of cv. Solarset were transplanted in each microplot 1 week after fumigation. A total of 32 kg/ha of nitrogen fertilizer in the form of granular 10-10-10 ($N\text{-}PO_2\text{-}K_2O$) was applied with 25% of the total amount incorporated preplant and the remaining divided into six weekly applications (Hochmuth et al., 1999). Halosulfuron was applied broadcast at the labeled rate 2 weeks after transplanting to manage nutsedge. Tomato roots from each microplot were removed 6 weeks after transplanting and the galls were indexed on a scale of 0 to 10 (0 = 0 galls and 10 = 100% of the roots galled) (Barker et al., 1986).

Soil texture for each treatment at each depth was determined using the hydrometer technique (Bouyoucos, 1951). A subsample from each microplot and each depth was taken 24 hours before fumigation and sent to the University of Florida Analytical Research Laboratory for determination of pH, organic matter, and electrical conductivity.

The data were subjected to analysis of variance, and regression analysis was used to determine nematode response to length of exposure to 1,3-D in the soil. The data were transformed with $\log_e (x + 1)$ before analysis, and only significant data ($P \leq 0.1$) are reported.

Results

In the compost-amended microplots at the 0-to-15-cm depth, the organic matter content was 2.0 to 2.4% in trial 1 and 1.9% to 3.0% in trial 2 (Table 1). Soil organic matter content in unamended plots ranged from 0.6% and 0.8% in the upper 15 cm of both trials. The soil texture for all the microplots was similar, with the percentage of sand ranging from 93.5% to 96.5% and only slight differences in the percentage of sand, silt, and clay observed at the three depths tested. Soil moisture from both amended and unamended soil was greater (17.1% to 18.4%) from samples taken at 30 to 45 cm deep than at the other depths (Table 2).

Roots of tomato grown in microplots with unamended soil and fumigated with 1,3-D had fewer galls (trial 1 = no galls, trial 2 = 1% of the root system galled) than roots from the untreated controls and roots from fumigated compost-amended soil (Table 3). The gall index from tomato roots grown in fumigated compost-amended soil was not different from the untreated controls for both trials (Table 3).

The number of galls per tomato root system from the soil bioassay decreased with increasing time of exposure to 1,3-D in compost-amended and unamended soils from the top 15 cm (Fig. 1A,B). In trial 1, an exposure period between 72 and 96 hours was required to eliminate all infective juveniles in unamended soil, whereas 96 hours of exposure was not sufficient to pre-

TABLE 1. Physical and chemical properties of compost-amended and unamended soil used in two microplot trials testing the efficacy of 1,3-dichloropropene (1,3-D) in the control of *Meloidogyne incognita*.

		Trial 1						Trial 2					
Soil type[a]	Depth	pH	%Sand	%Silt	%Clay	OM (%)	EC	pH	%Sand	%Silt	%Clay	OM (%)	EC
Untreated													
Compost-amended	0 to 15	5.9	95	2	3	2.4	0.2	6.9	96.5	0.5	3	3.0	0.1
	15 to 30	6.3	95	2	3	1.1	0.1	6.9	93.5	3.5	3	1.6	0.1
	30 to 45	6.5	96	1	3	1.3	0.1	7.0	94.5	2.5	3	0.6	0
Unamended	0 to 15	6.5	95	2.5	2.5	0.8	0.1	7.0	95	2.5	2.5	0.6	0.1
	15 to 30	6.5	94.5	2.5	3	0.6	0	7.1	94	4	2	0.5	0
	30 to 45	6.5	96	2	2	0.6	0	7.0	96	2	2	0.4	0
Fumigated													
Compost-amended	0 to 15	6.4	94	3	3	2.0	0.1	6.9	94	4	2	1.9	0.1
	15 to 30	6.7	95	3	2	1.0	0.1	7.0	93.5	3.5	3	0.8	0
	30 to 45	6.9	95	2.5	2.5	1.0	0.1	6.9	94	2	4	0.8	0.1
Unamended	0 to 15	6.5	94	2	4	0.6	0.1	7.0	94.5	2.5	3	0.7	0
	15 to 30	6.5	96.5	1.5	2	0.6	0.1	7.1	94.5	2.5	3	0.5	0
	30 to 45	6.5	94.5	2.5	3	0.6	0	7.1	94.5	2.5	3	0.5	0

[a] To prepare the compost-amended plots, soil was covered with a 10-cm depth of yard-waste compost, which was incorporated into the top 20 cm of soil in August 1995. The total amount of yard-waste compost added was ca. 500 t(m)/ha. The microplots then were infested with *Meloidogyne incognita* (Kofoid and White) Chitwood race 1.

vent root galling or kill all the J2 in compost-amended soil (Fig. 1A). An average of nine galls developed on tomato roots grown in the treated compost-amended soil. In trial 2, an exposure period between 72 and 96 hours prevented root galling (Fig. 1B). At 15 to 30 cm deep, the number of infective J2 decreased with longer exposure periods in the unamended soil (Fig. 2A,B). In trial 1, an exposure period between 48 and 72 hours eliminated infective J2. In the unamended soil, 49 to 474 galls developed on roots sampled 72 hours after fumigation. Only at 96 hours was there a reduction to an average of five galls per tomato root. In trial 2, the mean number of galls per root system decreased from 13.3 at 6 hours of exposure to no galls after 24 hours of exposure (Fig. 2B). At 96 hours, an average of 0.25 galls was detected, which was a single J2 that infected a root system. The number of galls at the deepest level (30–45 cm) in both trials did not decrease following fumigation. Numerous galls were observed on the bioassay plants at each post-fumigation sampling time and depth for both nonfumigated soils (data not shown).

TABLE 2. Gravimetric soil water content[a] at the time of fumigation with 1,3-dichloropropene for soils taken from 15, 30, and 45-cm depths in compost-amended and unamended soil in microplot for two trials.

		Trial 1	Trial 2
Soil type	Depth (cm)	Soil water (%)	Soil water (%)
Compost-amended	0 to 15	11.5	8.7
Compost-amended	15 to 30	12.1	10.8
Compost-amended	30 to 45	17.1	18.4
Unamended	0 to 15	7.2	11.1
Unamended	15 to 30	10.3	13.1
Unamended	30 to 45	18.0	18.2

[a]Soil water was determined on the same day the microplots were fumigated and the soil was dried at 36°C for 72 hours. Soil water was calculated using the following formula: % soil water = [(fresh weight − dry weight)/dry weight] × 100. Data are the mean of four replications.

DISCUSSION

The compost-amended and unamended soil used in this study had between a 94.8% and 96.5% sand composition—ideal for movement of 1,3-D throughout the soil profile. The sand content of the compost-amended and unamended soil was similar. After ca. 4 years the organic matter content in the top 30 cm of soil where the bulk of compost had been added was higher. The effect of 1,3-D on root-knot nematodes in compost-amended soil was clearly less than in unamended soil.

Diffusion of fumigants is greatly affected by soil organic matter because of their sorption to the colloidal organic matter (Siegel et al., 1951). As soil organic matter content increases, adsorption increases, the amount of fumigant available to diffuse into the soil air phase is

TABLE 3. The effect of 1,3-dichloropropene (applied broadcast at the rate of 112 liters/ha) on *Meloidogyne incognita* as indicated by a tomato root bioassay 6 weeks after transplanting in compost-amended and unamended soil in microplots.

	Trial 1	Trial 2
Soil type	Gall Index	Gall Index
Untreated		
Compost-amended	4.8 a	3.2 a
Unamended	8.5 a	1.4 a
Fumigated		
Compost-amended	4.9 a	2.1 a
Unamended	0 b	0.1 b

Data are the means of four replications. Means within columns followed by the same letter are not significantly different according to the Duncan's multiple-range test (trial 1 $P \leq 0.05$ and trial 2 $P \leq 0.1$).

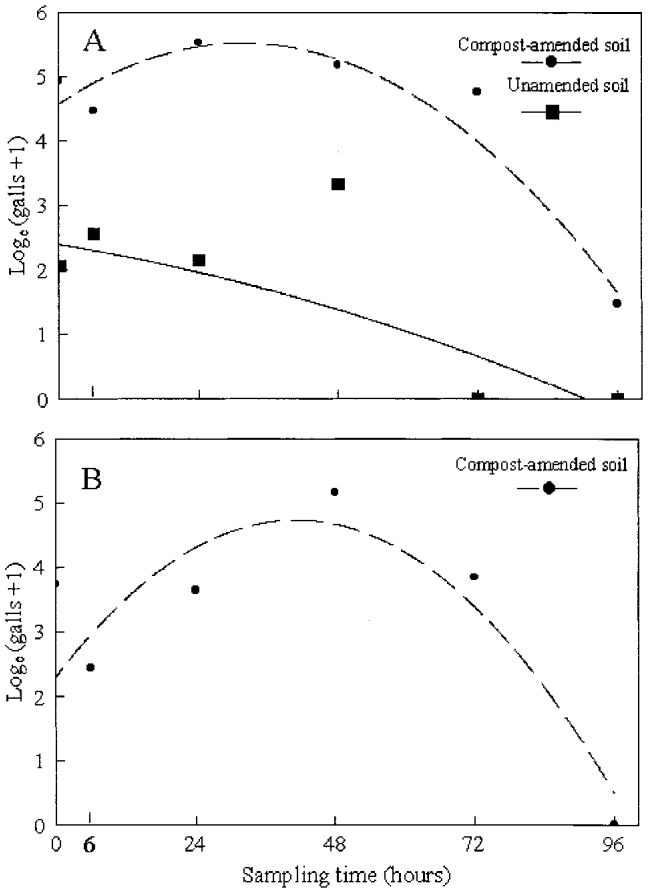

FIG. 1. The effect of exposure period after fumigation with 1,3-dichloropropene at 112 liters/ha on *Meloidogyne incognita* from 0 to 15 cm deep in microplots containing either unamended or compost-amended soil. Data are the log-transformed number of galls produced per root system on bioassayed tomato plants after 6 weeks. A) Trial 1. Unamended soil: $Y = 2.4 - 0.01X - 0.0001X^2$, $R^2 = 0.39$, $P < 0.05$; compost-amended: $Y = 4.6 + 0.06X - 0.01X^2$, $R^2 = 0.52$, $P < 0.05$. B) Trial 2. Compost-amended soil: $Y = 2.3 - 0.12X - 0.001X^2$, $R^2 = 0.38$, $P < 0.05$. Each data point is the mean of four replicates.

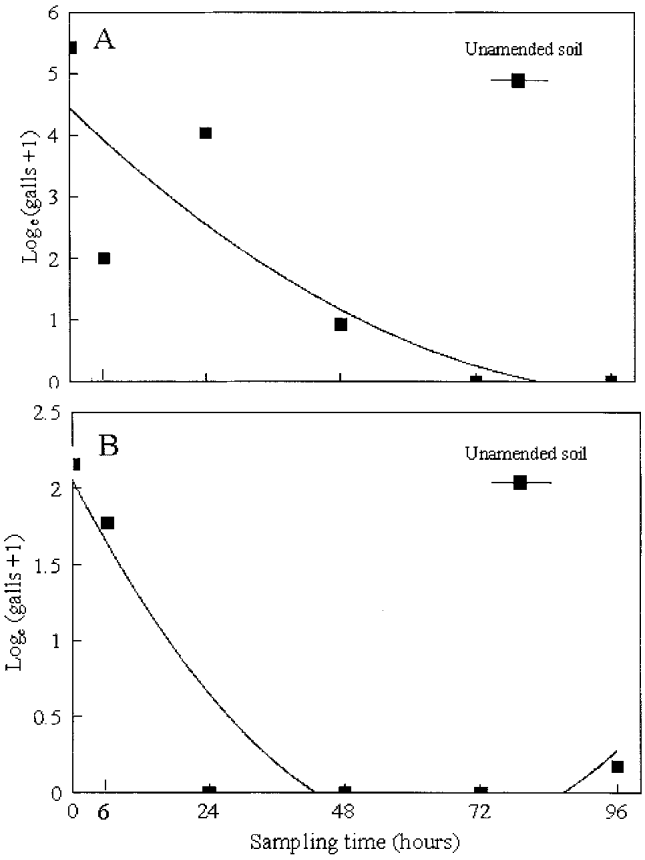

FIG. 2. The effect of exposure period after fumigation with 1,3-dichloropropene at 112 liters/ha on *Meloidogyne incognita* from 15 to 30 cm deep in microplots containing either unamended soil. Data are the log-transformed number of galls produced per root system on bioassayed tomato plants after 6 weeks. Gall index should not be log transformed. A) Trial 1. Unamended soil: $Y = 4.4 - 0.09X - 0.0004X^2$, $R^2 = 0.54$, $P < 0.01$. B) Trial 2. Unamended soil: $Y = 2.0 - 0.07X - 0.006X^2$, $R^2 = 0.38$, $P < 0.05$. Each data point is the mean of four replicates.

reduced (Lembright, 1990), and reliable fumigation of soil is more difficult to achieve (Goring, 1957; Leistra, 1970). Addition of composted organic matter may promote degradation of 1,3-D (Gan et al., 1998). Microbial degradation of 1,3-D was not measured in this study but could have a bearing on the higher survival rate of root-knot nematodes after fumigation in the compost-amended soils. Most effective fumigation occurs with high porosity throughout the soil so that the fumigant has the best chance to diffuse considerable distances before extensive sorption or decomposition occurs (Goring, 1957). Thomason and McKenry (1974) evaluated the diffusion pattern of cis-1,3-D in sandy loam soil with 0.6% organic matter vs. sandy loam with 2.2% and 2.6% organic matter in the form of chopped grass. They reported that the maximum concentration of 1,3-D in the vapor phase was lower in soil with 2.2% organic matter and lowest in 2.6% organic matter compared to soil with 0.6% organic matter.

1,3-Dichloropropene is a liquid that is fairly water soluble (2,200 µg/ml). Soils used for this study had high soil-water contents. With the exception of two soil samples, all had a water content greater than 10%. Soil-water content at field capacity for Arredondo soil is 7.3%, so the soil at the lower depths was saturated or nearly saturated. Because of the water solubility of 1,3-D and high soil-water content, the majority of the 1,3-D applied in the microplots would have been in the soil solution at the lowest depth (15–30 cm) rather than in the soil pore spaces. When 1,3-D is in solution phase, it may be degraded or escape into the atmosphere, or some of the chemical may be sorbed to soil surfaces. 1,3-Dichloropropene is subject to both chemical and microbial degradation. The half-life for 1,3-D in an aqueous dilute solution at 30 °C is 3.1 days (McCall, 1987). At the lower depths in our study, since the majority of 1,3-D was in soil solution and temperatures were in the range of 29 °C to 31 °C, chemical hydrolysis could have been substantial.

Youngson and Goring (1962) exposed root-knot nematodes to 1,3-D in sealed containers filled with

sandy soil at 21 °C for various exposure periods. The rates tested were 3, 6, 12, and 24 liters 1,3-D/ha, and exposure times were 8 hours, 1 day, and 14 days after fumigation. No control was observed after 8 hours of exposure for rates of 3, 6, and 12 liters/ha; however, at 24 liters of 1,3-D/ha, 78% of the J2 were killed. After 24 hours of exposure, J2 were still detected at the two lower rates, but none were detected at the two higher rates. Complete control of root-knot nematodes at all the rates was observed after 14 days (Youngson and Goring, 1962). In our study, a bioassay was performed because it is the most reliable method to determine the number of infective J2 remaining following treatment (McSorley and Parrado, 1983; Thomason et al., 1968). A negative response was observed between longer exposure periods and the number of infective J2 in the top 30 cm of soil. In the top 15 cm of unamended soil, an exposure period between 48 and 72 hours was necessary to achieve 100% mortality of infective J2. A similar trend was observed in the 15 to 30-cm profile. However, in trial 2, infective J2 were detected after 96 hours of exposure to 1,3-D.

In the top 15 cm of the fumigated compost-amended soil, more J2 escaped fumigation and remained infective. The exposure period required to attain 100% mortality was increased by 24 hours to 72 to 96 hours of exposure. However, in trial 1, a few nematodes escaped fumigation at all exposure periods tested, No control of J2 was observed at the 30 to 45-cm depth for unamended or amended soil, where elevated soil moisture likely restricted the movement of 1,3-D into the lower profile of the microplots. This is consistent with results obtained in the field by McKenry and Thomason (1974).

1,3-Dichloropropene at the rate of 112 liters/ha proved to be effective in controlling root-knot nematodes in unamended microplots. However, this treatment was not effective in compost-amended soil. Thus, caution must be exercised when amending compost or any form of organic matter to fields that may require 1,3-D fumigation to control plant-parasitic nematodes.

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