Efficacy of Sweep-Shank Fumigation with 1,3-Dichloropropene Against *Pratylenchus penetrans* and Subsequent Groundwater Contamination

R. LORIA, Department of Plant Pathology, Cornell University, Long Island Horticultural Research Laboratory, Riverhead, NY 11901; R. E. EPLEE, Whiteville Methods Development Center, P.O. Box 279, Whiteville, NC 28472; J. H. BAIER and T. M. MARTIN, Suffolk County Health Department, Hauppauge, NY 11788; and D. D. MOYER, Suffolk County Cooperative Extension, Riverhead, NY 11901

ABSTRACT

Loria, R., Eplee, R. E., Baier, J. H., Martin, T. M., and Moyer, D. D. 1986. Efficacy of sweep-shank fumigation with 1,3-dichloropropene against *Pratylenchus penetrans* and subsequent groundwater contamination. Plant Disease 70:42-45.

Populations of *Pratylenchus penetrans* in plots treated with a 92% solution of 1,3-dichloropropene (1,3-D) at 47, 70, 94, 117, or 140 L/ha of formulated material increased less than in control plots when this fumigant was injected under an untilled winter cover crop with a sweep-shank injector. Linear regressions of posttreatment *P. penetrans* populations or population changes against 1,3-D rates were significant ($P \leq 0.01$) at one of two locations. Fumigation at 140 but not 94 L/ha resulted in contamination of groundwater by *cis* and *trans* 1,3-dichloropropene within 68 days of application. Water samples taken 83 days after fumigation also contained 1,2-dichloropropane. Peak concentrations of these chlorinated hydrocarbons in groundwater occurred 83 days after fumigation. Abnormally heavy rainfall (11 cm) that occurred within 6 days of fumigant application probably reduced fumigant efficacy and enhanced pesticide leaching. The need for research to evaluate the potential for groundwater contamination by soil-applied pesticides is discussed.

Systemic insecticide/nematicides are commonly used for control of *Pratylenchus penetrans* on potato (*Solanum tuberosum*). The discovery of groundwater contamination by these pesticides at some locations, however, has caused considerable alarm and has led to regulatory action. Aldicarb is a groundwater contaminant in several states including New York, Wisconsin, Maine, Florida, Connecticut, Delaware, Maryland, New Jersey, Rhode Island, Virginia, and California (4). Consequently, the use of aldicarb has been banned in Suffolk County, NY, and Del Norte County, CA, and in several states (4). Oxyamyl and carbofuran, which are also carbamate insecticide/nematicides, were used as substitutes for aldicarb in Suffolk County, NY, until they too were found in groundwater (Suffolk County Health Department, *unpublished*) and were withdrawn from sale. Because carbamate insecticide/nematicides are not available for control of *P. penetrans* in Suffolk County, there is renewed interest in nematicidal soil fumigants.

The fumigant 1,3-dichloropropene (1,3-D) is effective for control of *P. penetrans* on potatoes (7,11). This fumigant is generally applied in the northeastern United States in the fall after potatoes are harvested and before a winter cover crop is planted. Fall fumigation is most convenient when the previous crop can be harvested early enough to allow time for winter cover crop establishment after fumigation. This practice is only possible in fields where early-maturing crops are grown. Unfortunately, the use of small grains as winter cover crops permits *P. penetrans* to increase on newly fumigated fields, since they are excellent hosts for this nematode (8). Spring fumigation of fields would reduce populations of nematodes that build up on winter cover crops. However, tillage operations recommended before fumigation are inconvenient, because potatoes are planted early in the spring immediately after fields are plowed.

Soil fumigants are usually applied to tilled soil, which maximizes dispersion of the fumigant; however, application of fumigants to untilled soil has been attempted with some success (9,18), even when nematodes were associated with living host roots (18). Sweep shanks allow application of pesticides as a broadcast swath below the soil surface, improving dispersion and efficacy (9). Smelt et al (13) showed that under some conditions, soil tillage before fumigant injection with a horizontal blade injector had no beneficial effect on fumigant dispersion. The objectives of this study were to evaluate control of *P. penetrans* by preplant sweep-shank fumigation with 1,3-D in untilled soil bearing a cover crop and to assess the potential for groundwater contamination by this pesticide when applied in this manner.

MATERIALS AND METHODS

All experiments were established in April 1983 in commercial potato fields in Suffolk County, NY. Soil types were Haven loam or Bridgehampton silt loam, which are both deep, well-drained to moderately well-drained soils with sand and gravel substrata. These soils are normally buffered at pH 5.0 and contain about 3–4% organic matter. 1,3-D (Telone II, 92%) was applied 8–12 cm below the soil surface with a sweep-shank fumigant applicator (Fig. 1). Seven sweep shanks were spaced 30 cm apart on a tool bar, which was used for fumigant delivery. A spray nozzle was mounted under each triangular-shaped shank. The shanks lifted the soils 3–5 cm, and the fumigant was sprayed in a plane below the shanks. A wavy cutting coulter was mounted directly in front of each sweep shank to facilitate shank movement through the soil, and a sectional packing roller was towed behind the shanks to seal the soil. A positive-displacement, ground-driven metering pump was used to deliver the fumigant, which was evenly distributed to the shanks by a manifold and metering orifices in line to each shank.

Efficacy evaluation. All plots (4 × 152 m) had a cover crop of rye (*Secale cereale*) at the time of fumigation. The six treatments were replicated six times in a completely randomized design at each of two locations. The treatments, applied 7 April 1983, consisted of five rates of 1,3-D (47, 70, 94, 117, and 140 L/ha of formulated material) and an untreated control. Soil samples were taken to determine pretreatment (P_i) nematode populations 2–3 days before fumigation. Twenty subsamples, each consisting of a 2.5-cm-diameter soil core taken 15 cm deep, were collected from each plot. Subsamples from each plot were mixed thoroughly, and nematodes were extracted from 100 cm^3 of soil and root fragments by the Baermann pie pan technique (6) and collected on a 45-μm sieve.

Posttreatment (P_f) nematode samples were taken as just described 20–22 days after fumigation. Both posttreatment populations and population changes were transformed, using the $\log_{10}$ transformation, and regressed against 1,3-D rates to determine the statistical significance of the effects of the fumigation treatments.

Groundwater monitoring. Evaluation of pesticide leaching was done in commercial potato fields similar to those

Accepted for publication 12 June 1985.

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked "*advertisement*" in accordance with 18 U.S.C. § 1734 solely to indicate this fact.

used for efficacy studies. The groundwater was within 3.0–4.5 m of the soil surface of the 2-ha plots. Two rates of 1,3-D (94 and 140 L/ha of formulated material) were tested separately (locations C and D, respectively). Location C had been planted to oats (*Avena sativa*) the previous fall, whereas location D had been planted to rye. Plots were fumigated on 6 April 1983 as described previously. Four wells were installed on the periphery of the field at each location: one upstream to monitor incoming groundwater and three downstream of the anticipated flow of groundwater from the treated fields. The wells were installed using a machine-operated continuous flite hollow-stem auger. The casings and well points were 5 cm in diameter, and the points were continuous wound stainless steel, 0.6 m long, installed 0.6 m below the water table. A centrifugal pump was used to collect water samples. On each sampling date, wells were pumped for 30 min before water samples were collected in screw-cap vials (40 ml) with Teflon-faced septa. Water samples were immediately stored at 0 C and analyzed within 30 hr of collection. The protocol suggested by the Environmental Protection Agency for purgeable hydrocarbon analysis (Method 601, Federal Register, Vol. 44, No. 233, 3 December 1979) was followed to determine concentrations of *cis* and *trans* 1,3-D and 1,2-dichloropropane (1,2-D), an impurity in the Telone II formulation. Rainfall data were obtained from within 10 km of the fumigation sites at the National Weather Service Station at Bridgehampton, NY.

RESULTS

The soil temperature at all locations was about 10 C at the time of fumigation. Soils at locations A, C, and D were moist but favorable for tillage, whereas soil moisture at location B was slightly higher. The sweep-shank application equipment functioned in the desired manner with no evident operational problems. The wavy coulters cut through the 15-cm cover crop and ground stubble, permitting clean operation of the sweep shank. The sweeps at the bases of the shanks operated smoothly and evenly at 8–12 cm deep. These sweeps lifted the soil and cover crops about 3–5 cm as they passed horizontally through the soil, permitting an even distribution of the fumigant by the flood nozzles located underneath the sweeps. The sod and soil settled back to their original position and were packed firmly by the sectional rolling packer.

Control of *P. penetrans*. The average pretreatment population of *P. penetrans* extracted per 100 cm^3 of soil and root fragments was 28 at location A and 36 at location B. The rye cover crop showed some foliar chlorosis in fumigated plots but was not killed by the fumigant at any of the rates tested. Reproduction of *P. penetrans* probably occurred on rye roots between pretreatment and posttreatment sampling. However, *P. penetrans* populations increased less on rye roots in 1,3-D-treated plots than in control plots (Table 1) during the 22–23 days between sampling dates at both locations. Linear regressions of both $\log_{10}(P_{f+1})$ and $\log_{10}(P_{f+1}) - \log_{10}(P_{i+1})$ against rates were significant ($P \leq 0.01$) at location A (Table 1) but not at location B (Table 1). However, *P. penetrans* was detected after fumigation with 1,3-D at all rates tested at both locations.

Groundwater monitoring. Neither 1,3-D nor 1,2-D was found in pretreatment water samples or in upstream wells at either location. Levels of these materials in all water samples taken after

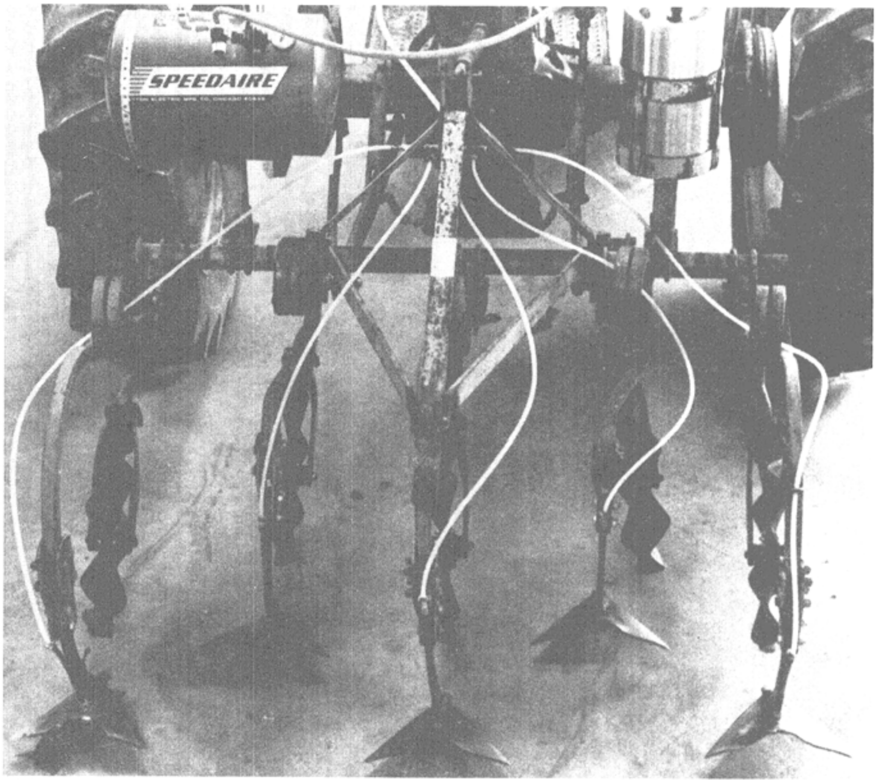

Fig. 1. Sweep-shank fumigant applicator. Fumigant was delivered to spray nozzles beneath the triangular-shaped shanks.

Table 1. Effects of sweep-shank fumigation of untilled soil with five rates of 1,3-dichloropropene (1,3-D) on *Pratylenchus penetrans* populations at locations A and B[a]

	Location A		**Location B**	
1,3-D (L/ha formulated material)	**Posttreatment *P. penetrans* populations (P_f)[b]**	**Change in *P. penetrans* populations ($P_f - P_i$)[c]**	**Posttreatment *P. penetrans* populations (P_f)[d]**	**Change in *P. penetrans* populations ($P_f - P_i$)[e]**
0	84	+57	73	+46
47	45	+13	80	+34
70	21	−6	84	+19
94	24	−11	51	−7
117	23	+4	36	−8
140	7	−21	37	+28

[a] Nematodes were extracted from 100 cm^3 of soil and root fragments by the Baermann pie pan technique. Data are means of six replicates.

[b] Regression equation of $\log_{10}(P_{f+1})$, Y, on 1,3-D rates, X, is $Y = 1.88 - 0.0780X$, $F_{1,34} = 19.4$ ($P \leq 0.01$).

[c] Regression equation of $\log_{10}(P_{f+1}) - \log_{10}(P_{i+1})$, Y, on 1,3-D rates, X, is $Y = 0.522 - 0.0706X$, $F_{1,34} = 11.8$ ($P \leq 0.01$).

[d] Regression equation of $\log_{10}(P_{f+1})$ on 1,3-D rates is not significant ($P \leq 0.05$).

[e] Regression equation of $\log_{10}(P_{f+1}) - \log_{10}(P_{i+1})$ on 1,3-D rates is not significant ($P \leq 0.05$).

fumigation with 1,3-D at 94 L/ha (location C) were also below the detection threshold of 2 ppb. However, both 1,3-D and 1,2-D were found in groundwater after fumigation with 1,3-D at 140 L/ha (location D). Both *cis* and *trans* 1,3-D appeared in one downstream well 68 days after fumigation (Table 2). The concentrations of these stereoisomers peaked at 83 days and were still found in groundwater samples 138 days after fumigation. Water samples taken from the same downstream well at location D 83, 104, 138, and 188 days after fumigation also contained 1,2-D. Rainfall immediately after fumigation was unseasonably high; 10.6 and 18.5 cm of precipitation occurred within 5 and 12 days, respectively, of 1,3-D application (Fig. 2). A total of 32.1 cm of rain fell after fumigation and before the pesticide was first detected in samples of groundwater in wells on the peripheries of treated fields.

DISCUSSION

Nematode control leveled off at 1,3-D rates of 117 L/ha at location B (Table 1). This poor control at the higher fumigant rates suggests that inadequate dispersal of the fumigant may have limited efficacy; high soil moisture at location B could have reduced fumigant dispersal (10,12). Better control was obtained at location A (92% at 140.3 L/ha), where soil moisture was observed to be lower than at location B. Also, the fumigant might have been more effective at both locations if substantial precipitation had not occurred soon after fumigation, since excess water can leach 1,3-D through the soil profile (17). These data indicate that useful levels of nematode control may be attainable with sweep-shank fumigation in untilled soil and suggest that additional research may be justified. The influence of cover crop type and soil characteristics on the efficacy of this technique merit special attention.

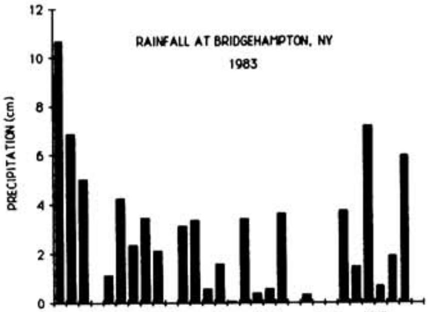

Fig. 2. Rainfall at Bridgehampton, NY, from 6 April to 31 October 1983.

The critical dosage level for contamination by 1,3-D appeared to be between 94 and 140 L/ha under the conditions of this study. However, since these two rates were applied to separate fields, it is difficult to draw conclusions about the effect of pesticide rate. Soil moisture, organic matter, regional differences in rainfall, or other factors might have differentially influenced leaching of 1,3-D in these fields. The pattern of pesticide contamination in the downstream well at location D was typical of that resulting from a pulse input of a contaminant. The concentration of 1,3-D and 1,2-D increased as groundwater flowed from the fumigated area towards the well, then gradually declined as the plume of pesticide-contaminated groundwater passed by the well. The relatively rapid decline of the concentration of these contaminants in the well indicated that only the edge of the pesticide plume was detected or that the pesticide was degrading in the groundwater as it moved toward the well.

We believe this is the first report of groundwater contamination by *cis* and *trans* 1,3-D when applied as a soil fumigant. The shallow water table in fumigated fields coupled with unusually high rainfall soon after fumigation provided ideal conditions for movement of 1,3-D through the soil profile to the groundwater. Low soil temperatures, relatively course-textured soils, and limited dispersion of the fumigant in soil may also have contributed to pesticide leaching. Though leaching of 1,3-D was demonstrated only under conditions that were very favorable for movement through the soil, these data show that the potential for groundwater contamination by 1,3-D exists. 1,2-D has been found in excess of recommended action levels (50 ppb) in groundwater wells in Suffolk County after summer fumigation with 1,3-D at rates of 337 L/ha (Suffolk County Health Department, *unpublished*). Use of 1,3-D in areas and under conditions where leaching is likely to occur should be considered carefully. Research is being conducted in Suffolk County to evaluate the potential for groundwater contamination when this fumigant is injected into tilled soil in the fall at rates of 140 L/ha or lower.

The problem of groundwater contamination by both fumigant and nonfumigant nematicidal pesticides, though unforeseen by pest control specialists as late as 1978 (16), is now a growing concern (1). Aldicarb was first discovered in groundwater in Suffolk County in 1979 and has since been detected in groundwater at other locations in New York and in several other states (4). Ethylene dibromide, dibromochloropropane, and 1,2-D have been found in excess of recommended action levels in well waters used for drinking in California (2). Unfortunately, available data do not allow accurate prediction of when or where pesticide use will result in groundwater contamination (3,5). Pest control specialists involved in testing and recommending soil-applied pesticides should be cognizant of groundwater pollution problems. Efforts should be made to engage in cooperative research with soil water specialists to determine the potential for pesticide pollution of groundwater.

Research is needed to determine rates and methods of pesticide application that are both effective and nonpolluting. Such research is best undertaken before widespread contamination occurs and regulatory action results in the loss of additional agricultural pesticides. Modeling techniques are being used to integrate the physical, chemical, and biological processes that determine the environmental fate of soil-applied pesticides (14). Experiments should be designed to provide data needed for such modeling efforts (15).

ACKNOWLEDGMENTS

We thank B. A. Ludlow, R. Carter, the Suffolk County Health Department well drilling crew, and K. Hill, director, Public Health Lab, Suffolk County, for technical assistance. We also thank D. H. Harris,

Table 2. Pretreatment and posttreatment concentrations (ppb) of *cis* and *trans* 1,3-dichloropropene (1,3-D) and 1,2-dichloropropane (1,2-D) in groundwater samples taken from wells at location D, which was fumigated with 1,3-D (140 L/ha of formulated material) on 6 April 1983

	Sampling dates (1983)[a]								
Well position	**5 Apr.**	**17 May**	**6 Jun.**	**13 Jun.**	**28 Jun.**	**19 Jul.**	**22 Aug.**	**11 Oct.**	**14 Nov.**
Upstream	ND	ND	ND	ND	ND	ND	ND	NS	ND
Downstream	ND	ND	ND	19[b] 18[c]	130[b] 140[c] 10[d]	73[b] 72[c] 10[d]	21[b] 19[c] 6[d]	5[d]	ND
Downstream	ND	ND	ND	ND	ND	ND	ND	ND	ND
Downstream	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a] ND = below detection capability (<2 ppb), NS = no sample.

[b] *cis* 1,3-Dichloropropene.

[c] *trans* 1,3-Dichloropropene.

[d] 1,2-D.

commissioner, Suffolk County Health Department, for cooperation throughout the study.

LITERATURE CITED

1. Abelson, P. H. 1984. Groundwater contamination. Science 224:673.
2. Anonymous. 1984. Pestic. Toxic Chem. News 12(20):7.
3. Anonymous. 1984. Pestic. Toxic Chem. News 12(21):36-37.
4. Anonymous. 1984. Pestic. Toxic Chem. News 12(23):38-39.
5. Anonymous. 1984. Pestic. Toxic Chem. News 13(5):12.
6. Barker, K. R., chairman. 1978. Determining nematode population responses to control agents. Pages 114-125 in: Methods for Evaluating Plant Fungicides, Nematicides, and Bactericides. American Phytopathological Society, St. Paul, MN. 141 pp.
7. Cetas, R. C., and Harrison, W. B. 1963. Evaluation of soil fumigants for the control of early maturity wilt of potatoes on Long Island. (Abstr.) Phytopathology 53:347-348.
8. Dunn, R. A., and Mai, W. F. 1973. Reproduction of *Pratylenchus penetrans* in roots of seven cover crop species in greenhouse experiments. Plant Dis. Rep. 57:728-730.
9. Eplee, R. E. 1984. Annual Report Methods Development Center, 1983. U.S. Dep. Agric. PP&Q, APHIS, Whiteville, NC.
10. Lewis, G. D., and Mai, W. F. 1963. Temperature and moisture in relation to the toxicity of 1,3-dichloropropene to *Ditylenchus dipsaci* (Kühn) Filipjev in organic soil. Plant Dis. Rep. 47:1097-1101.
11. Miller, P. M., and Edgington, L. V. 1963. Potato: Nematode injury & scurf, vascular browning of tubers and weeds. Fungic.-Nematic. Tests 18:83.
12. Munnecke, D. E., and Van Gundy, S. D. 1979. Movement of fumigants in soil, dosage responses, and differential effects. Annu. Rev. Phytopathol. 17:405-429.
13. Smelt, J. H., Leistra, M., Sprong, M. C., and Nollen, H. M. 1974. Soil fumigation with dichloropropene and metham-sodium: Effect of soil cultivations on dose pattern. Pestic. Sci. 5:419-428.
14. Steenhuis, T. S., Van der Marel, M., and Pacenka, S. 1984. A pragmatic model for diagnosing and forecasting groundwater contamination. Proc. Practical Application of Groundwater Models. Nat. Water Well Assoc.
15. Wagenet, R. J., and Rao, P. S. C. 1985. Basic concepts of modeling pesticide fate in the crop root zone. Weed Sci. In press.
16. Wilson, J. H., Jr. 1978. Legal, human, and environmental aspects of nematode control chemicals. Pages 135-137 in: Methods for Evaluating Plant Fungicides, Nematicides, and Bactericides. American Phytopathological Society, St. Paul, MN. 141 pp.
17. Youngson, C. R. 1982. Post-fumigation irrigation for control of root-knot nematodes with Telone II soil fumigant. Down to Earth 38:28-36.
18. Youngson, C. R., Turner, G. O., and O'Melia, F. C. 1981. Control of plant parasitic nematodes on established tree and vine crops with Telone II soil fumigant. Down to Earth 37:6-10.