Supplement to Journal of Nematology 24(4S):669–680. 1992.

Management of Plant-parasitic Nematodes with a Chitin–Urea Soil Amendment and Other Materials[1]

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Abstract: Field trials were conducted with a chitin–urea soil amendment and several other nematicides on four crop–nematode combinations: tomato–*Meloidogyne incognita;* potato–*Meloidogyne chitwoodi;* walnut–*Pratylenchus vulnus;* and brussels sprouts–*Heterodera schachtii.* Significant ($P \leq 0.10$) nematode population reductions were obtained with the chitin–urea soil amendment in the trials on potato and walnut. In the trials on brussels sprouts and on tomato, phytotoxicity occurred at rates of 1,868 and 1,093 kg/ha, respectively. Significant ($P \leq 0.10$) nematode reductions were also obtained with metham sodium on potato; with 1,3-D on tomato and brussels sprouts; and with sodium tetrathiocarbonate, XRM 5053, fenamiphos, ethoprop, LX1075-05, LX1075-07, and SN 109106 on tomato. The following materials did not provide significant nematode control under the conditions of the particular experiments: metham sodium, oxamyl, and *Yucca* extract on tomato; and dazomet granules on brussels sprouts.
Key words: Brassica oleracea gemmifera, brussels sprouts, chemical control, *Heterodera schachtii, Juglans hindsii, Meloidogyne chitwoodi, M. incognita,* nematode, potato, *Pratylenchus vulnus, Solanum tuberosum,* tomato, walnut.

For many years, a preplant application of 1,3-dichloropropene has been the most widely used method for preplant management of nematodes in annual and perennial crops in California. The potential for loss of this material makes continuing research on the use of alternatives necessary. Since the loss of the registration of 1,2-dibromo-3-chloropropane (DBCP), there have been no postplant materials registered for use on many crops in California. The recent registration by the United States Environmental Protection Agency of a chitin–urea soil amendment (ClandoSan 618) for both pre- and postplant use against nematodes prompted the need to obtain efficacy data for this material on crops grown in California. The nematicidal effect of chitin–urea is thought to be partially due to nematode toxicity resulting from the production of ammonia from the decomposition of urea (12,19) and partly due to the stimulation of nematode-parasitic fungi with chitinolytic properties (10,14).

Our objective was to conduct field trials with the chitin–urea soil amendment on nematodes important on tomato (*Lycopersicon esculentum*), potato (*Solanum tuberosum*), brussels sprouts (*Brassica oleracea gemmifera*), and walnut (*Juglans hindsii*), and to compare its efficacy to other experimental and registered materials.

MATERIALS AND METHODS

Tomato experiment: This experiment was conducted at the University of California South Coast Field Station in a sandy loam soil infested with the root-knot nematode *Meloidogyne incognita* (Kofoid & White) Chitwood. There were 20 treatments (including a control) in a randomized complete block design with four replicates per treatment. Each plot was a single row 7.6 m long by 1.5 m wide. The plants were irrigated with a subsurface drip irrigation system. The drip irrigation tubing (Drip In

Received for publication 3 September 1991.
[1] Funded in part by the California Potato Research Advisory Board, DowElanco Chemical Corporation, Unocal Chemicals Division, Nor-Am Chemical Company, and Landis International. Mention of a trade name, proprietary product, or vendor does not constitute a guarantee of a product and does not imply its approval to the exclusion of other products or vendors that may also be suitable.
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The assistance of our grower cooperators is appreciated.

Irrigation Company, Fresno, CA) was buried 30 cm beneath the surface with emitter spacings 30 cm apart with an application rate of 2 liters/hour per emitter. All treatments were applied prior to transplanting 6-week-old 'UC-82' processing tomato plants in single-row plots 30 cm apart. Twelve treatments were applied on 25 July 1989, 2 weeks prior to transplanting either to allow for activation of the nematicidal properties of the materials or to allow phytotoxic materials to disperse. The other seven treatments were applied on 14 August 1989, one day prior to transplanting.

The 25 July 1989 treatments included the chitin–urea amendment (ClandoSan 618, Igene Biotechnology, Inc., Columbia, MD) at a rate of 1,093 kg product/ha spread by hand in a 30-cm band down the center of the bed and incorporated with a power tiller to a depth of 20 cm, and 1,3-dichloropropene (1,3-D, Telone II, Dow-Elanco, Indianapolis, IN) injected 30 cm deep with a hand applicator in two rows spaced 30 cm apart on the top of the bed at a rate of 92 liters/ha. Ten treatments were injected into the drip irrigation tubing with a piston pump (Inject-O-Meter, Model I-70, Clovis, NM). Five of these were applied at a concentration of 200 ppm a.i. in water over a 2-hour period: 1,3-D plus emulsifier (XRM 5053, Dow-Elanco, Indianapolis, IN), oxamyl (Vydate L, Dupont, Wilmington, DE), fenamiphos (Nemacur 3, Mobay, Kansas City, MO), ethoprop (Mocap EC, Rhone-Poulenc, Monmouth Junction, NJ), and LX1075-07 (75% EC, Landis International, Valdosta, GA). This application rate was equivalent to 16 liters a.i./ha of each material. Metham sodium (Vapam, ICI Americas, Wilmington, DE) was applied in water at 1,000 ppm a.i. over a 2-hour period (82 liters a.i./ha). Sodium tetrathiocarbonate (Enzone, GY-81, Unocal, West Sacramento, CA) was applied in water at 500 ppm for 1, 2, 3, or 4 hours (155, 310, 465, and 620 liters of product/ha, respectively). These last four treatments were equivalent to applying 50 liters of sodium tetrathiocarbonate or 20 liters of carbon disulfide/ha/hour.

The 14 August 1989 treatments included a granular organophosphate material LX107-05 (10G, Landis International, Valdosta, GA), applied at rates of 2 and 3 kg a.i./ha in 30-cm-wide bands down the center of the bed. Granules were incorporated 20 cm deep with a rolling cultivator following surface application.

Three materials were diluted in water and applied with a hand sprayer as a 30-cm-wide band down the center of the bed followed by incorporation as described above. A *Yucca* extract (Pent-a-Vate, Lindsay, CA) was applied at a rate of 39 liters/ha. A wettable powder (SN 109106, Nor-Am, Kansas City, MO) was applied at rates of 19.8 and 39.6 kg a.i./ha. An organophosphate liquid (LX107-07, Landis International, Valdosta, GA) was applied at rates of 2 and 3 kg a.i./ha.

Tomato seedlings were transplanted on 15 August 1989. Plants were inspected visually on 31 August 1989 and rated for vigor and evidence of phytotoxicity of the materials. Two visual ratings on a scale from 0 to 10 were made for the plants in each plot. In the first, a 10 indicated a high proportion of the plants in the plot were weak or wilted. In the second, a 10 indicated a high proportion of the plants exhibited white or brownish tip burn.

Tomatoes were hand-harvested on 15 November 1989, and the fresh weight of fruit was recorded. Roots were dug with a shovel and root gall ratings from 0 (no galling) to 4 (100% galled) were made on each of four plants per plot and averaged for a plot rating. Soil samples consisting of eight 2.5-cm-diameter cores 30 cm deep were taken at harvest from each plot. Nematodes were extracted from a 350-cm^3 subsample using a modified semiautomatic elutriator and sugar flotation technique (5).

Potato experiment: This experiment was conducted in a field in the Tulelake/Klamath Basin of California with a history of infestation with Columbia root knot nematode, *Meloidogyne chitwoodi* Golden et al., and a lesion nematode, *Pratylenchus neglectus* (Rensch) Filipjev & Schuurmans Stekhoven. The silty clay loam soil contained 12% stable organic matter. All treatments were applied 2 weeks prior to planting 'Russet Burbank' seed pieces. Plots were 0.9 m wide by 18 m long arranged in a randomized complete block design with four replicates per treatment.

There were nine treatments (including a control). Chitin–urea was applied in a 30-cm-wide band down the center of the bed at rates of 1,121 and 1,186 kg/ha. The material was incorporated to a depth of 20 cm with a rolling cultivator. A single concentration (1,000 ppm a.i. in water) of metham sodium was applied over three different lengths of time (0.5, 1, and 2 hours), with or without 3 hours of previous irrigation (preirrigation), for a total of six treatments. The drip irrigation tubing used was the same as for the previous experiment except that it was placed on the surface of preformed beds. As before, all six metham sodium applications were injected into the drip irrigation tubing with a piston pump. Following treatment application, the drip irrigation tubing was removed and the trial was watered with overhead sprinklers.

Potatoes were machine-harvested on 18 October 1988. Infestation with *M. chitwoodi* produces a blemish on the surface of potato tubers, which makes them unsuitable for fresh market use (21). At harvest, tubers were divided into blemished and unblemished groups. Within these groupings, they were graded into the following categories: greater than 227 g, 113 to 227 g, less than 113 g, and culls (tubers unsuitable for market due to growth deformities not caused by nematodes). Tuber yield, grade, and the percentage of each grade with nematode blemish were recorded. Nematode population levels in all plots were determined from soil samples taken on 5 May (pretreatment) and 19 October (postharvest). Each sample was composed of ten 2.5-cm cores to a depth of 30 cm. Nematodes were extracted from soil as described previously (5).

The citrus nematode (*Tylenchulus semipenetrans* Cobb) was used as a biological indicator to provide an initial measure of the control obtained with metham sodium. Citrus-nematode-infested soil was obtained from an orange grove in Riverside, California. Fifty cm^3 of infested soil were placed in 9 cm by 13 cm muslin bags (Hubco Soil Sample Bags, Forestry Suppliers, Inc., Jackson, MS). Prior to applications, two bags were buried (one at 15 cm and one at 30 cm) in each plot to be treated with metham sodium and in control plots. One bag was also placed at the 15-cm depth in each of the chitin–urea treated plots to evaluate the assay for monitoring chitin–urea efficacy in future experiments. Bags were recovered 3 days following treatment. Citrus nematode survival was determined by counting juveniles that passed through the filter paper of a Baermann funnel (3) within a 72-hour period.

Brussels sprouts experiment: This experiment was conducted in a grower's field in Santa Cruz County in an Elder loam soil known to be infested with sugarbeet cyst nematode, *Heterodera schachtii* Schmidt. There were six treatments including a control in a randomized complete block design with four replicates per treatment. Each replicate was a single row 0.9 m wide by 5 m long. The experiment was sprinkler irrigated as part of a larger field. All applications were made on 24 May 1988, 2 weeks prior to transplanting 'Valient' brussels sprouts (23,712 plants/ha) in a single row per bed at 40 cm spacing.

Treatments included two rates of chitin–urea (1,121 and 1,868 kg/ha), two rates of dazomet (Basamid, Clean Crop, Loveland/Hopkins Industries, Loveland, CO) granules (56 and 112 kg/ha), 1,3-D at 126 liters/ha, and a control. Chitin–urea was applied in a 30-cm-wide band and incorporated 18 cm deep with a shovel. The dazomet was applied in a 30-cm-wide band down the center of the bed and raked into the upper 5 cm, and a water seal was applied with a sprinkler can. The 1,3-D was applied 30 cm deep with a single shank down the center of the bed.

Soil samples from control plots were taken prior to plot establishment. All replicates were sampled 1 month posttreatment on 23 June 1988 and again just prior to harvest on 14 November 1988, when the yield from each plant was measured. Each soil sample was composed of ten 2.5-cm cores to a depth of 30 cm. Juveniles were extracted from soil using a modified semiautomatic elutriator and sugar flotation technique (5). Eggs were extracted via sieving followed by alcohol–glycerol flotation and maceration of cysts (11).

Walnut experiment: This trial was conducted in a sprinkler-irrigated, 12-year-old orchard of 'Payne' walnut on 'Paradox' hybrid rootstock growing in Cogna loam soil in San Joaquin County, with a tree spacing of 9 m both between and within rows. This orchard had previously been found to have a high population of lesion nematode, *Pratylenchus vulnus* Allen & Jensen. The trial was conducted in a randomized, complete block design with three treatments and seven individual tree replicates per treatment. Seven groups of three trees each were selected, with each group having a similar trunk diameter, height, and vigor. One of each of the three treatments was randomly assigned to a tree within each group. The treatments were chitin–urea at 1,893 kg/ha, urea at 443 kg/ha (to partition out the effect of this material in the chitin–urea product), and an untreated control. The chitin–urea and urea were spread by hand in a 6-m-diameter band around each tree and rototilled to a depth of 20 cm.

Pretreatment soil samples from control plots were taken on 4 November 1988. Posttreatment samples from all plots were taken on 4 April, 2 June, and 23 October 1989. Each sample was composed of ten 2.5-cm cores to a depth of 30 cm. Nematodes were extracted from soil using a modified semiautomatic elutriator and sugar flotation technique (5).

Results of all experiments were subjected to analysis of variance followed by calculation of least significant difference (LSD) values at $P = 0.05$ and $P = 0.10$ for comparison of means (15).

RESULTS

Tomato experiment: Two weeks after transplanting, phytotoxicity symptoms of wilt or tip burn were evident (Table 1). Some plants in all treatments except the 2- and 3-hour applications of sodium tetrathiocarbonate were rated as weak or wilted. The only treatment in which the rating was higher ($P = 0.05$) than for the control was chitin–urea. Very few of the plants in this treatment survived until harvest. Plants with tip burn were only present in the treatments with LX107-05 and LX107-07. The phytotoxicity rating was higher ($P = 0.05$) than the control for three of the five treatments (the drip irrigation application and the two granular applications) with this material.

The root gall rating ranged from 0 to 1.4 (Table 1) and was higher ($P = 0.05$) than the control in only one treatment (LX107-07 at 2 kg a.i./ha). In three treatments (metham sodium, LX107-07 at 2 kg a.i./ha, and LX107-07 at 3 kg a.i./ha), galling was higher ($P = 0.05$) than for 1,3-D, which is the most widely used commercial preplant treatment.

The number of root-knot nematode juveniles present in soil at harvest was lower ($P = 0.05$) than the control for the standard 1,3-D injection application, the 4-hour sodium tetrathiocarbonate drip application, the drip irrigation applications of fenamiphos, ethoprop, LX1075-07, and the chitin–urea application (Table 1). In addition to the above treatments, at $P = 0.10$ the following treatments resulted in nematode densities lower than those in the control: the 1-hour application of sodium tetrathiocarbonate, the XRM 5053 application, the high rate of SN 109106, and both rates of LX107-05. The number of root-knot juveniles present in soil at harvest was higher ($P = 0.05$) than the 1,3-D injection

TABLE 1. Effects of nematicide treatments on phytotoxicity, root galling, density of *Meloidogyne incognita* juveniles, and tomato yield.

Nematicide treatment	Type of application	Rate/ha of product or a.i.†	Phytotoxicity rating‡		Gall rating§	*Meloidogyne incognita* (juveniles/liter soil)	Yield (kg/ha)
			Vigor	Tip burn			
Control	None		0.50	0.00	0.45	1,000	37,018
1,3-D	Injection	92 liters a.i.	1.25	0.00	0.00	0	40,614
Sodium tetra-thiocarbonate	Drip 1 hr, 500 ppm	155 liters Product	0.75	0.00	0.13	200	37,368
Sodium tetra-thiocarbonate	Drip 2 hrs, 500 ppm	310 liters Product	0.00	0.00	0.00	575	33,947
Sodium tetra-thiocarbonate	Drip 3 hrs, 500 ppm	465 liters Product	0.00	0.00	0.00	513	38,070
Sodium tetra-thiocarbonate	Drip 4 hrs, 500 ppm	620 liters Product	0.25	0.00	0.03	88	39,386
XRM 5053	Drip 2 hrs, 200 ppm	17 liters a.i.	0.50	0.00	0.08	250	38,947
Metam-sodium	Drip 2 hrs, 1,000 ppm	82 liters a.i.	0.75	0.00	1.03	1,063	43,421
Oxamyl	Drip 2 hrs, 200 ppm	16 liters a.i.	0.50	0.00	0.00	413	35,877
Fenamiphos	Drip 2 hrs, 200 ppm	16 liters a.i.	1.25	0.00	0.00	0	38,070
Ethoprop	Drip 2 hrs, 200 ppm	16 liters a.i.	1.25	0.00	0.00	0	30,175
LX1075-07	Drip 2 hrs, 200 ppm	16 liters a.i.	0.75	6.25	0.00	0	35,351
Chitin–urea	Granule, till	1,093 kg Product	9.50	0.00	0.00	13	6,316
Yucca extract	Spray, till	39 liters Product	1.00	0.00	0.33	625	38,246
SN 109106	Spray, till	19.8 kg a.i.	0.25	0.00	0.03	423	42,632
SN 109106	Spray, till	39.6 kg a.i.	0.25	0.00	0.03	225	36,140
LX107-05	Granule, till	2 kg a.i.	1.00	7.75	0.00	289	42,193
LX107-05	Granule, till	3 kg a.i.	1.50	5.00	0.03	250	37,368
LX107-07	Spray, till	2 kg a.i.	0.75	0.75	1.40	575	40,614
LX107-07	Spray, till	3 kg a.i.	0.25	0.75	0.98	350	43,246
LSD (P = 0.05):			1.45	2.51	0.92	830	8,342

Data are means of four replications.

† Rates are expressed as the amount of material that would actually have been applied per hectare of crop. Broadcast rates would be approximately five times higher.

‡ For vigor, 0 = healthy plant, 10 = dead plant. For tip burn, 0 = no tip burn, 10 = all plants in plot exhibiting tip burn.

§ Galling rated on a scale of 0 = no galling to 4 = 100% galled.

treatment for the control and for the metham sodium treatment.

The weight of tomatoes harvested ranged from a low of 6,313 kg/ha in the chitin–urea treatment to a high of 43,421 kg/ha for the metham sodium treatment (Table 1). Only the chitin–urea treatment had a yield lower (P = 0.05) than the control. Two treatments (chitin–urea and ethoprop) had yields significantly lower (P = 0.05) than the 1,3-D injection treatment.

Potato experiment: The citrus nematode biological indicators placed 15 cm deep in the metham sodium plots indicated that control (P = 0.05) was obtained with all applications except the lowest rate that was preirrigated (Table 2). However, at the 30-cm depth, nematode reductions (P = 0.05) compared to the control plots were obtained only at the highest rates tested, with or without preirrigation. The biological indicators did not demonstrate any improvements in control as a result of preirrigation.

The numbers of root-knot nematodes

TABLE 2. Effects of nematicides on nematode population densities in the potato experiment.

Nematicide treatment	Rate of product/ ha†	Previous irrigation‡	Length of application (hours)	*Tylenchulus semipenetrans* (number/50 ml soil)		*Meloidogyne chitwoodi* (juveniles/liter of soil)		*Pratylenchus neglectus* (number/liter of soil)	
				15-cm depth	30-cm depth	Pretreatment	Postharvest	Pretreatment	Postharvest
Control	0	–	0	1,144	980	157	3,021	1,112	1,354
Metham sodium	98 liters	–	0.5	0	536	100	1,511	442	770
Metham sodium	196 liters	–	1	468	368	29	342	285	998
Metham sodium	392 liters	–	2	0	0	86	670	228	1,767
Metham sodium	98 liters	+	0.5	630	782	58	983	570	898
Metham sodium	196 liters	+	1	12	496	29	670	356	983
Metham sodium	392 liters	+	2	0	0	72	1,297	242	1,340
Chitin–urea	1,121 kg	–	0	788	No indicators	43	1,026	770	1,397
Chitin–urea	1,868 kg	–	0	1,352	No indicators	157	2,024	926	1,767
LSD				656	865	109	1,704	356	878
P for LSD				0.05	0.05	0.10	0.05	0.05	0.10

Data are means of four replications.

† Rate are expressed as the amount of material that would actually have been applied per hectare of crop. Broadcast rates would be approximately three times higher. All metham sodium applications were at a concentration of 1,000 ppm a.i. in water.

‡ Length of previous irrigation was 3 hours on the day preceding nematicide application.

per plot at pretreatment were not different at $P = 0.05$, but some treatments were lower than the control at $P = 0.10$ (Table 2). Following harvest, root-knot juveniles were lower ($P = 0.05$) than the control for all treatments except the lowest rate of metham sodium without preirrigation and the highest rate of chitin–urea. There were no differences ($P = 0.05$) in Pf/Pi ratios (Pf/Pi = final nematode population divided by initial nematode population) for *M. chitwoodi* (data not shown).

Because pretreatment samples for a number of the treatments were lower ($P = 0.05$) than the control, data for *Pratylenchus neglectus* are more difficult to interpret (Table 2). There were no differences in control at $P = 0.05$ for any of the materials or rates tested. The Pf/Pi ratio = 16.3 for the highest preirrigated rate of metham sodium was higher ($P = 0.05$) than that of the control, Pf/Pi = 1.5. For the highest rate of metham sodium not preirrigated, the Pf/Pi ratio = 11.2 was higher than that of the controls at $P = 0.10$.

Within the unblemished grouping of tubers (Table 3), no treatments were different ($P = 0.10$) from controls within any category except culls. Within culls, the weight of tubers from the chitin–urea treatment was greater ($P = 0.05$) than for the controls. Within the blemished tubers, there were no significant differences between the treatments and the control at $P = 0.05$ in any grading categories. At $P = 0.10$, the weight of blemished tubers in plots with the lowest rate of metham sodium that was not preirrigated was greater than that in the control for tubers greater than 227 g and less than 113 g (Table 4). Also for this treatment, a greater ($P = 0.10$) overall percentage of tubers was blemished than for the control. There were no differences ($P = 0.10$) in total combined yields of all tubers for each treatment (Table 4).

Brussels sprouts experiment: There were no differences ($P = 0.10$) in the number of eggs of *H. schachtii* with treatment either 1 month after treatment or at harvest (Table 5). One month after treatment, there was a decrease ($P = 0.05$) in the number of juveniles in the 1,3-D treated plots compared to all other treatments. Although there was no decrease ($P = 0.10$) in either nematode eggs or juveniles, there was a significant increase ($P = 0.05$) in yield following the dazomet treatments at both rates compared to the chitin–urea treatments.

Walnut experiment: The only significant ($P = 0.10$) population reduction in this study occurred on the 2 June 1989 sampling date (Table 6). At that time, the populations of *P. vulnus* were lower ($P = 0.05$) in the chitin–urea-treated plots than in the untreated control. Yield data were not obtainable for this experiment.

Discussion

In three of the four experiments (potato, tomato, and walnut), chitin–urea reduced nematode population levels. In the other experiment (brussels sprouts), there were no effects of the chitin–urea material on the nematode populations. In the tomato experiment, the material resulted in visible phytotoxicity, and most plants in the treated plots died prior to harvest. The low numbers of nematodes present in the chitin–urea treatment at harvest could be due to lack of host plants to support a population. In the brussels sprouts experiment, phytotoxicity resembling fertilizer injury was observed in several of the chitin–urea-treated plots 2 weeks following transplanting. Although phytotoxicity was not observed at harvest, the lowest yields occurred in the two chitin–urea treatments. Though not required by the label, phytotoxicity could have been reduced and efficacy improved by a thorough wetting of the plots after treatment. This would have given the material time to break down, provide some nematode control, and allow phytotoxic materials to disperse before transplanting.

In the brussels sprouts experiment, average pretreatment counts on 24 May in the control plots were 62 juveniles and 17,394 eggs per liter of soil (Table 5). One month later (2 weeks following planting), there were 875 juveniles and 6,856 eggs. Evidently, planting of the crop and/or irri-

TABLE 3. Effects of nematicides on yield of unblemished potato tubers.

Nematicide treatment	Rate of product/ha†	Previous irrigation‡	Length of application (hours)	Unblemished tubers (kg/ha)				
				>227 g	113–227 g	<113 g	Culls	Total
Control	0	−	0	4,360	17,641	7,534	2,556	32,091
Metham sodium	98 liters	−	0.5	3,381	15,536	7,057	2,590	28,565
Metham sodium	196 liters	−	1	4,191	14,839	8,371	2,704	30,105
Metham sodium	392 liters	−	2	3,478	16,185	8,277	2,117	30,057
Metham sodium	98 liters	+	0.5	4,865	16,782	8,037	2,378	32,062
Metham sodium	196 liters	+	1	2,920	15,265	8,538	2,521	29,244
Metham sodium	392 liters	+	2	4,683	17,700	8,488	1,689	32,561
Chitin–urea	1,121 kg	−	0	4,801	14,976	7,639	3,936	31,352
Chitin–urea	1,868 kg	−	0	5,005	15,688	7,247	3,081	31,021
LSD				1,785	3,094	1,872	1,257	3,878
P for LSD				0.10	0.10	0.10	0.05	0.10

Data are means of four replications.

† Rates are expressed as the amount of material that would actually have been applied per hectare of crop. Broadcast rates would be approximately three times higher. All metham sodium applications were at a concentration of 1,000 ppm a.i. in water.

‡ Length of previous irrigation was 3 hours on the day preceding nematicide application.

TABLE 4. Effects of nematicides on yield of blemished potato tubers.

Nematicide treatment	Rate of product/ha†	Previous irrigation‡	Length of application (hours)	Blemished tubers (kg/ha)					Total yield (kg/ha)	Tubers with blemish (percentage)
				>227 g	113–227 g	<113 g	Culls	Total		
Control	0	–	0	164	843	224	112	1,344	33,434	3.99
Metham sodium	98 liters	–	0.5	909	1,152	818	325	3,204	31,768	9.52
Metham sodium	196 liters	–	1	0	30	0	0	30	30,135	0.1
Metham sodium	392 liters	–	2	0	438	281	49	769	30,825	2.42
Metham sodium	98 liters	+	0.5	227	341	332	171	1,071	33,133	3.49
Metham sodium	196 liters	+	1	72	239	128	159	597	29,841	1.95
Metham sodium	392 liters	+	2	0	214	44	77	334	32,895	0.99
Chitin–urea	1,121 kg	–	0	120	517	190	207	1,033	32,385	3.35
Chitin–urea	1,868 kg	–	0	459	673	285	173	1,590	32,611	4.74
LSD ($P = 0.10$):				620	776	524	240	1,962	3,774	5.8

Data are means of four replications.

† Rates are expressed as the amount of material that would actually have been applied per hectare of crop. Broadcast rates would be approximately three times higher. All metham sodium applications were at a concentration of 1,000 ppm a.i. in water.

‡ Length of previous irrigation was 3 hours on the day preceding nematicide application.

TABLE 5. Effects of nematicide treatments on densities of *Heterodera schachtii* and yield of brussels sprouts.

Nematicide treatment	Rate of product/ha†	Eggs/liter of soil: One month after treatment	Eggs/liter of soil: At harvest	Juveniles/liter of soil: One month after treatment	Juveniles/liter of soil: At harvest	Yield (kg/ha)
Control		6,856	24,403	875	7,250	31,527
Chitin–urea	1,121 kg	6,899	19,154	838	4,313	29,375
Chitin–urea	1,868 kg	9,363	21,875	713	7,750	29,267
Dazomet	56 kg	7,049	34,966	750	6,725	35,938
Dazomet	112 kg	6,835	28,731	613	8,900	36,799
1,3-D	126 liters	6,706	22,047	113	7,938	35,400
LSD		6,592	13,375	447	4,133	5,113
P for LSD		0.10	0.10	0.05	0.05	0.05

Data are means of four replications. Pretreatment samples taken from untreated control plots on 26 May 1988 contained means of 17,394 eggs and 60 juveniles per liter of soil.
† Rates are expressed as the amount of product that would actually have been applied per hectare of crop. Broadcast rates would be approximately three times higher.

gation stimulated hatching of eggs. At harvest, there was an increase in both juveniles and eggs to 7,250 and 24,403, respectively. In this experiment, 1,3-D reduced nematode juveniles in the soil but did not appear to provide control of the eggs within cysts. Similar levels of control were found in several samples taken from the grower's field surrounding the experimental plot.

The increase in yield in dazomet-treated plots in the absence of nematode control may be due to an effect on either soil fungi or soil insects. This area has a history of infestation with club root (*Plasmodiophora brassicae*), which could have been affected by the chemical treatment. Growers receive approximately $0.57/kg for brussels sprouts. The increases in yield as a result of dazomet treatments in this experiment would have returned $3,000/ha additional gross income for a grower. As in the tomato experiment, the performance of both chitin–urea and dazomet could probably have been improved by a more thorough wetting of the soil following applications, although this is not required by the labels of either product.

In the tomato experiment, the following materials not currently registered for use on this crop in California provided significant levels of nematode control: sodium tetrathiocarbonate, fenamiphos, ethoprop, XRM 5053, LX1075-05, LX1075-07, and SN 109106. The phytotoxicity observed with LX107-05 and LX1075-07 was temporary and did not appear to affect subsequent yields. Additional work would be needed with all of these materials to optimize rates and timing of applications.

Two materials currently registered for use on tomato through drip irrigation sys-

TABLE 6. Effects of chitin–urea and urea on density of *Pratylenchus vulnus* on walnuts.

Treatment	Rate of product (kg/ha)†	*Pratylenchus vulnus*/liter of soil: April	June	October
Control		2,757	1,779	3,064
Urea	443	2,785	1,550	3,521
Chitin–urea	1,893	2,700	1,065	3,100
LSD		1,288	739	1,807
P for LSD		0.10	0.05	0.10

Data are means of seven replications. Pretreatment samples taken from untreated plots in November 1988 contained a mean of 3,186 *P. vulnus* per liter of soil.
† Rates are expressed as the amount of product that would actually have been applied per hectare of crop. Broadcast rates would be approximately three times higher.

tems (oxamyl and metham sodium) did not provide nematode control under the conditions of this study. For oxamyl, the label recommends more frequent applications at lower rates than were used in the present study. For metham sodium, although label rates were used, beds were not at 50% of field capacity in the top 5 to 8 cm as recommended on the label. Following these recommendations was not feasible under the conditions of this experiment. Also, our experience in other situations (e.g., preirrigation for metham sodium in the potato experiment) indicates that these extra steps are not always necessary. Although it did not appear to provide significant nematode control, highest yields (though not statistically significant) were obtained in the metham sodium treatment, possibly due to the control of soil fungi or soil insects, which were not monitored in this study.

In the potato experiment, metham sodium applied through a drip irrigation system provided significant control of Columbia root-knot nematode and of citrus nematode biological indicators, whether or not the beds were preirrigated. Although recommended on the label, preirrigation may not be needed in the particular soil type being studied here because of the soil's ability to retain approximately twice its weight in water. For the biological indicators, increasing the rate and the length of the application increased the depth of penetration of the material. Previous research with flood and furrow applications of this chemical has shown a similar relationship (4). As a fumigant, metham sodium has been shown to move only 8 to 10 cm from the point of injection (8,16). In order to optimize control with this material, other methods such as movement with water or multiple, closely spaced injection points are needed to aid dispersal.

There are many reports of experiments with chitin soil amendments (6,7,9,10,13, 14,17–20). Most of these experiments have been conducted either in greenhouses or in small field microplots and have indicated greater nematicidal activity than in the present experiments. All treatments in our experiments were within label rates and ranged from 1,121 to 1,892 kg/ha. At a cost of approximately $1.50 to $2.11/kg (1,2), costs to growers would have ranged from $1,682/ha to $3,992/ha. These costs are 3 to 10 times higher than for any other currently registered nematicides on the crops tested.

It is encouraging that industry is developing additional nematicides and continuing to search for new active ingredients. Some of these are potentially as effective as 1,3-D, although for one or more reasons (e.g., cost, spectrum of activity, ease of use, reliability, toxicity to nontarget organisms) none of those tested in the present research appear to be direct substitutes for 1,3-D. Increasing the spectrum of available nematicides will be advantageous to growers in some ways, such as allowing them to more closely tailor a particular chemical to a treatment situation, but will also require additional knowledge with respect to the optimum conditions for using each chemical.

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