Supplement to Journal of Nematology 25(4S):758–767. 1993.

Management of *Pratylenchus penetrans* on Oriental Lilies with Drip and Foliar-applied Nematicides[1]

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Abstract: *Pratylenchus penetrans* is a pest for producers of oriental lilies in northern California. Concern over groundwater contamination from 1,2-dichloropropane following shank injections of 1,3-dichloropropene-1,2-dichloropropane mixture and granular applications of aldicarb prompted testing for alternative methods of controlling *P. penetrans.* In field trials, nematicides applied by drip irrigation (ethoprop, fenamiphos, oxamyl, sodium tetrathiocarbonate, water extracts of marigold and vetch, and 1,3-D plus emulsifier) were tested with and without foliar applications of oxamyl. Nematode populations were reduced ($P = 0.05$) relative to controls in soil or roots on one or more sampling dates by all drip-applied nematicides except the plant extracts. On some sampling dates, additional reductions ($P = 0.05$) occurred as a result of three foliar applications of oxamyl. Foliar-applied oxamyl alone also reduced ($P = 0.05$) nematodes in soil or roots. Lily bulb weight was not affected ($P = 0.05$) by chemical treatments.
Key words: chemical control, 1,3-dichloropropene, ethoprop, fenamiphos, lesion nematode, *Lillium* spp., marigold, nematicide, nematode, oriental lily, oxamyl, *Pratylenchus penetrans, Tagetes* spp., sodium tetrathiocarbonate, vetch, *Vicia* sp.

The lesion nematode *Pratylenchus penetrans* is a pest in lily production (9), including oriental lily (*Lillium* spp. hybrid cv. Lucie Wilson) production in Humboldt County, California. The climate is characterized by cool summers with coastal fog, mild winters, and an average annual rainfall of 190 cm (falling mostly from October to March). Cool soil temperatures, high water tables, and acidic soils contribute to the potential for groundwater contamination by pesticides in the area (19).

Bulb plantings commonly are rotated with pasture grasses (19). Bulbs are typically ca. 8-cm-d and planted 20 cm deep in February or March. Stems emerge within a few weeks. Roots grow not only from the base of the bulb but also from the underground portion of the stem, growing upward out of the bulb top to the soil surface. The bulbs are harvested at ca. 13-cm-d in September and sold to "bulb forcers" for cut flower production in greenhouses. Smaller bulbs and bulblets produced on the underground stem are saved for replanting the following year. Bulb quality is judged visually for size and apparent health of the root system. At planting, nematodes are typically present both in the field soil and within roots remaining on bulbs from the last growing season. These roots remain because growers believe that old roots must be present for healthy growth of new roots.

For nematode control, growers have traditionally used preplant fumigation with a mixture of 1,3-dichloropropene (1,3-D) and 1,2-dichloropropane (1,2-D) plus at-planting applications of a carbamate or organophosphate nematicide. After 1,2-D and aldicarb were found in groundwater in 1982, practices changed to preplant fumigation with 1,3-D and at-planting applications of fenamiphos (6). In 1986, after reports of deep soil contamination with fenamiphos, the manufacturer withdrew its registration for use on bulbs. From that time until April 1990, 1,3-D and phorate were used. At present, restricted materials use permits for 1,3-D are not issued in California because of concern over air pollution. The only materials currently available for use on lilies in California are metam-

Received for publication 4 September 1992.
[1] This study was funded in part by the USDA-ES Smith-Lever IPM Project, DowElanco Chemical Corporation, and Unocal Chemicals Division. 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–cooperator in Humboldt county is appreciated.

sodium, tarped methyl bromide, chloropicrin, and phorate.

Oxamyl is the only nematicide registered for foliar application (on several crops), which should reduce the potential for groundwater contamination compared with soil application. In some cases, multiple applications at weekly intervals improved nematode control compared with a single application (20). Despite these advantages, oxamyl is not widely used in California. Application of nematicides via drip irrigation tubing may also minimize the potential for groundwater contamination because the grower can position tubing in the root zone to limit dispersal of nematicides. Further, it permits multiple applications of smaller amounts of nematicides at times when it might be difficult to move conventional application equipment into planted fields (2,17). Our objective was to determine the effectiveness of drip irrigation applications of several promising nematicides with or without foliar applications of oxamyl.

Materials and Methods

One experiment was conducted in 1987 and two in 1988. Trials were established in a grower's field (49% sand, 34% silt, 17% clay; 6.4% stable organic matter, pH 5.9) with a history of infestation with the lesion nematode *P. penetrans.* Planting stock was ca 8-cm-d bulbs that were too small to sell the previous season. Bulbs were planted 20 cm deep in March and harvested in September. Except for the nematicide applications, the experimental areas were managed by the grower as part of the commercial field. The 1987 trial was sprinkler irrigated (except during nematicide applications) and the 1988 trials were drip irrigated throughout the growing season. Trial areas were not watered for at least 1 week following applications, although in some cases rainfall occurred within shorter periods.

Treatments consisted of drip irrigation applications of several nematicides and foliar sprays of oxamyl (24% a.i.). In each experiment, plots were 1 row (0.92 m) wide by 3 m long, arranged in four randomized complete blocks with foliar treatments as a split plot (i.e., one-half of a 6 m long area treated with a nematicide via drip irrigation received a foliar treatment). The drip irrigation tubing was laid on top of the beds (after plants had emerged in 1987 and preemergence in 1988) and had emitters spaced 30 cm apart with application rates of 2 liters/hour per emitter (Experiments 1 and 2, Drip In Irrigation Company, Fresno, CA) or delivered thru twin-wall line-source emitter tubing with orifices spaced 10 cm apart at a rate of 1 liter/m of tube per hour (Experiment 3, Raintape, Rainbird, El Cajon, CA) (16). Drip irrigation treatments were either applied via motor-driven syringe injection devices (17) or injected into the drip irrigation tubing with a piston pump (Model I-70, Inject-O-Meter, Clovis, NM). In Experiments 1 and 2, each drip-irrigation treated plot (6 m long) was divided in half, and one half was randomly chosen to receive the foliar oxamyl applications. Three foliar applications of oxamyl at 2.24 kg a.i./ha in 189 liters/ha of water were applied weekly beginning 19 June in 1987 and 1 June in 1988, with a hand sprayer (Model 2001A, B and G Equipment Co., Plumsteadville, PA). The nozzle was adjusted to give a fine spray and was held 15 cm above the top of the leaves.

Treatment effects were evaluated through estimations of nematode population densities in soil and root samples. Soil samples comprised eight 2.5-cm-d cores per plot taken 30 cm deep. Nematodes were extracted from a 400-cm^3 soil subsample with a modified elutriation and sucrose centrifugation technique (4). Nematodes were also extracted from roots removed from the base of the bulbs (five per plot) and from stems. Roots were weighed and placed in an intermittent-mist chamber for 72 hours (3). Nematodes were identified and counted at ×45 magnification. On some sample dates, an average bulb weight or stem bulblet count was obtained for five bulbs from each plot.

In the 1987 experiment, there were 16 treatments (including a control) comprising seven nematicides applied via drip irrigation, and the same treatments with three foliar applications of oxamyl. Drip applications were conducted on 18 June 1987 and included sodium tetrathiocarbonate (32% a.i.) at 200 or 400 ppm a.i. in water for 30 or 60 minutes (54, 108, 108, and 215 liters product/ha, respectively), 1,3-D plus emulsifier (60% a.i.) at 5 liters product/ha applied at 100 ppm a.i. in water for 30 minutes, ethoprop (69.6% a.i.) at 5 liters product/ha applied at 100 ppm a.i. in water for 30 minutes, and oxamyl at 15 liters product/ha applied at 100 ppm a.i. in water for 30 minutes.

In 1987, in addition to soil and root samples, citrus nematode (*Tylenchulus semipenetrans*) was used as a biological indicator of the control provided by the nematicides. Citrus nematode-infested soil was obtained from an orange grove in Riverside, California. Infested soil (50 cm^3) was placed in 9 cm by 13 cm muslin bags (Hubco Soil Sample Bags, Forestry Suppliers, Jackson, MS). Before nematicide applications, two bags were buried (one at 15 cm and one at 30 cm) in each plot. Bags were recovered 3 days after 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.

In the 1987 experiment, samples were taken pretreatment on 18 June (soil only), on 17 July (soil and stem roots), and at harvest on 24 September (soil, and stem and bulb roots). On 24 September, an average bulb weight was obtained for 5 bulbs per plot. A visual rating of average top growth per plot was based on a scale from 0 (dead) to 5 (plants very green and healthy-looking).

Experiment 2 (1988) also had 16 treatments (including a control) comprising seven nematicides applied via drip irrigation, and the same treatments with three foliar applications of oxamyl. Drip treatments included sodium tetrathiocarbonate at 400 and 800 ppm a.i. at 108 and 215 liters product/ha/application, respectively; 1,3-D plus emulsifier at 5 liters product/ha/application applied at 100 ppm a.i. in water; oxamyl at 15 liters product/ha/application applied at 100 ppm a.i. in water; ethoprop at 5 liters product/ha/application applied at 100 ppm a.i. in water; fenamiphos (35% a.i.) at 9 liters product/ha/application applied at 100 ppm a.i. in water; and water extracts of either marigolds or vetch (1137 liters/ha/application) (prepared by M. V. McKenry, University of California, Riverside, from 18 grams/liter of plant material) (14). All drip applications were for 30 minutes each, and all except marigold–vetch were repeated four times during the growing season. Treatment dates were 14 April, 23 May, 5 July, and 31 August 1988. Because of limited availability of the materials, marigold extract was applied on 13 April 1988, and vetch extract was applied on 5 July 1988.

In this experiment, samples were taken pretreatment on 13 April (soil and bulb roots), 9 May (soil and bulb roots), 5 July (soil, and stem and bulb roots), 31 August (soil and stem and bulb roots), and 22 September (soil and stem and bulb roots). The mean bulb weight and stem bulblet counts were recorded on 31 August and 22 September.

The third experiment consisted of only one treatment plus a control. Oxamyl was applied three times at monthly intervals via drip irrigation at 100 ppm a.i. for 60 minutes (4.5 liters/ha/application). The first application was made on 23 May 1988.

In experiment 3, samples were taken on 1 June (soil and bulb roots), 5 July (soil and stem and bulb roots), 9 September (soil and bulb roots), and 22 September (soil, stem and bulb roots, bulb weight, and number of bulblets per stem).

Results were subjected to analysis of variance followed by orthogonal mean comparisons (P = 0.05 and 0.10) testing each treatment versus the control (1). To stabilize variances, nematode counts (x) were transformed to $\log_{10}(x + 1)$ prior to analysis.

RESULTS

Phytotoxicity was not observed in any treatments. A preplant root sample, taken in March from planting stock bulbs for experiment 1, contained 22 *P. penetrans*/g. Soil temperature at the time of treatment was 15 C. In pretreatment soil samples (18 June) no differences were found in lesion nematode levels among plots (Table 1). None of the treatments provided reductions (P = 0.05) in the citrus nematode bioindicators (data not shown). On 17 July, densities of lesion nematode were higher (P = 0.05) in the 1,3-D plus emulsifier treatment than in the control. Due to a sampling error at harvest, soil samples were taken from the combined drip and drip plus foliar treatments, and the only reduction (P = 0.05) in lesion nematode soil populations was detected in the oxamyl-treated plots.

At harvest, numbers of lesion nematodes in bulb roots were lower (P = 0.05) in oxamyl-treated plots with or without foliar applications (Table 1) than in the control. On 17 July, the only reduction (P = 0.05) in lesion nematodes from stem roots was in the foliar-application plots. At harvest, *P. penetrans* were fewer in the foliar treatment (P = 0.05). At harvest, there were no differences in bulb weight among treatments. Plots visually rated by growers as higher than the controls were drip alone and drip plus foliar oxamyl (P = 0.01) and ethoprop plus foliar oxamyl (P = 0.05).

In general, numbers of lesion nematodes in soil and in roots were lower in the 1988 experiments than the 1987 experiment. In experiment 2, no differences (P = 0.05) in nematode numbers were found among pretreatment soil samples. Soil temperatures at time of treatment were 12, 18, 21, and 15 C on 14 April, 23 May, 5 July, and 31 August, respectively. On 9 May, lesion nematodes were fewer in plots treated with sodium tetrathiocarbonate at 400 ppm a.i. (P = 0.05) than in control plots. On 5 July, numbers of lesion nematodes were lower (P = 0.05) than the control in three treatments that had received foliar oxamyl applications: 1,3-D plus emulsifier and both sodium tetrathiocarbonate treatments. On 31 August, *P. penetrans* was not detected in soil samples from three treatments that had received foliar applications (oxamyl, ethoprop, and fenamiphos) and in the oxamyl drip treatment. At harvest, soil densities of *P. penetrans* were lower (P = 0.05) than the control in six of the eight drip plus foliar treatments (exceptions were marigold–vetch and the low rate of sodium tetrathiocarbonate) plus the drip-only applications of ethoprop and fenamiphos (Table 2).

There were no differences (P = 0.05) in numbers of lesion nematodes in bulb roots from pretreatment samples in experiment 2 (Table 2). As in the soil, numbers of lesion nematodes in bulb roots were lower on 9 May in plots treated with sodium tetrathiocarbonate at 400 ppm a.i. (P = 0.05) than in the control plots. On 5 July, nematode numbers in bulb roots were lower (P = 0.05) than in the controls in three of the drip plus foliar treatments (ethoprop, fenamiphos, and the high rate of sodium tetrathiocarbonate) and ethoprop alone. On 31 August, *P. penetrans* in bulb roots were fewer (P = 0.05) than in the control plots in all but plots treated with the low rate of sodium tetrathiocarbonate and marigold–vetch without foliar applications. At harvest, bulb-root densities of lesion nematodes remained lower than the control plots (P = 0.05) in plots treated with oxamyl, ethoprop, and fenamiphos alone, and oxamyl and fenamiphos with foliar applications (Table 2).

On 5 July, numbers of lesion nematodes extracted from stem roots were lower (P = 0.05) than the control plots in those treated with oxamyl with and without foliar application, and ethoprop and the high rate of sodium tetrathiocarbonate

TABLE 1. Effect of nematicide treatments on densities of *Pratylenchus penetrans* in soil and roots and growth ratings of oriental lilies (1987).

				Pratylenchus penetrans						
				Soil (number/liter)			Bulb	Stem (number/gram of root)		Growth rating #
Treatment	Rate of product†	Drip irrigation‡	Foliar treatment§	18 June	17 July	24 Sept	24 Sept	17 July	24 Sept	24 Sept
Control	0	0	–	433	766	706	437	239	4,732	2.75
Sodium tetrathiocarbonate	54	200–30	–	343	566	544	402	211	416	2.75
Sodium tetrathiocarbonate	108	200–60	–	673	724	513	451	290	569	2.25
Sodium tetrathiocarbonate	108	400–30	–	655	991	706	360	675 ^	460	2.00 ^
Sodium tetrathiocarbonate	215	400–60	–	844	957	531	601	267	505	2.25
1,3-D plus emulsifier	5	100–30	–	444	1,698 *	806	235 ^	453	447	2.75
Ethoprop	5	100–30	–	428	699	669	369	321	297	3.50 ^
Oxamyl	15	100–30	–	444	649	263 *	153 *	255	496	4.75 **
Control	0	0	+		891		379	130 *	136 *	2.25
Sodium tetrathiocarbonate	54	200–30	+		866		280	240	507	2.50
Sodium tetrathiocarbonate	108	200–60	+		824		470	256	552	2.25
Sodium tetrathiocarbonate	108	400–30	+		624		494	365	391	2.25
Sodium tetrathiocarbonate	215	400–60	+		849		439	280	420	2.50
1,3-D plus emulsifier	5	100–30	+		774		482	247	816	2.50
Ethoprop	5	100–30	+		699		352	388	518	3.75 *
Oxamyl	15	100–30	+		566		247 *	192	330 ^	4.50 **

Data are means of four replications.

† Rates are expressed in liters/ha per application, the amount of material that would actually be applied. Broadcast rates would be approximately three times higher.

‡ Rates are ppm a.i. followed by the length of time in minutes over which the material was applied.

§ "+" = three foliar applications of 2.4 kg a.i./ha applied at weekly intervals beginning 19 June; "–" = no foliar treatments.

Growth ratings were subjective, made by two independent observers on a scale from 0 = dead to 5 = green and healthy looking, and averaged for each treatment.

**, *, and ^ indicate that means within columns are significantly different from control without foliar treatment at $P = 0.01$, $P = 0.05$ or $P = 0.10$, respectively. Except for growth rating, analysis was performed on $\log_{10}(X + 1)$ transformed data where X = the nematode count.

TABLE 2. Effect of nematicide treatments on densities of *Pratylenchus penetrans* in soil and roots of oriental lilies (1988).

				Pratylenchus penetrans												
									Bulb					Stem		
				Soil (number/liter)					(number/gram of root)							
Treatment	Rate of product†	Drip irrigation‡	Foliar treatment§	13 April	9 May	5 July	31 Aug	22 Sept	13 April	9 May	5 July	31 Aug	22 Sept	5 July	31 Aug	22 Sept
Control	0	0	–	25	167	50	325	150	19	7	15	18	26	11	81	48
1,3-D plus emulsifier	5	100	–	75	50	38	188	88	253	4	4 ^	7 *	13	2	44 *	51
Oxamyl	15	100	–	13	117	13 ^	0 *	38 ^	20	8	20	0 *	2 *	0 *	1 *	5 *
Ethoprop	5	100	–	25	100	63	63	0 *	73	4	1 *	1 *	1 *	5	1 *	0 *
Fenamiphos	9	100	–	113	183	13 ^	25	13 *	8	5	7	0 *	2 *	4	2 *	14
Marigold/vetch	1,137	33,500	–	63	50	75	1038	238	22	7	10	25	38 ^	3	99	147 *
Sodium tetrathio-carbonate	108	400	–	38	50 *	50	138	63	18	8 *	32	23	38	30	19 *	10 ^
Sodium tetrathio-carbonate	215	800	–	38	83	75	200	63	57	3	34	6 *	15	2 ^	6 *	148
Control	0	0	+			25	63	75 *			19	2 *	23	12	25 *	44
1,3-D plus emulsifier	5	100	+			0 *	38	38 *			7	0 *	2 ^	4	2 *	1 *
Oxamyl	15	100	+			13 ^	0 *	25 *			13	0 *	1 *	1 *	0 *	2 *
Ethoprop	5	100	+			38	0 *	0 *			1 *	0 *	3 ^	0 *	0 *	0 *
Fenamiphos	9	100	+			13 ^	0 *	13 *			0 *	*	0 *	1 ^	0 *	0 *
Marigold/vetch	1,137	33,500	+			25	88	50			18	2 *	13	10	5 *	36
Sodium tetrathio-carbonate	108	400	+			0 *	100	25 ^			19	1 *	11	3	0 *	6 *
Sodium tetrathio-carbonate	215	800	+			0 *	50 ^	13 *			1 *	0 *	12	0 *	1 *	0 *

Data are means of four replications.

† Rates are expressed in liters/ha per application, the amount of material that would actually be applied. Broadcast rates would be approximately three times higher.

‡ Rates are ppm a.i. All drip irrigation applications were for 30 minutes.

§ "+" = three foliar applications at a rate of 2.24 kg a.i./ha applied at weekly intervals in June; "–" = no foliar treatments.

*,^ indicate means within columns are significantly different at $P = 0.05$, or $P = 0.10$, respectively. Analysis performed on $\log_{10}(X + 1)$ transformed data where X = the nematode count.

with foliar applications (Table 2). On 31 August, numbers of lesion nematodes extracted from stem roots were lower (P = 0.05) than in the control plots in all plots except those treated with marigold–vetch without foliar application. At harvest, numbers of nematodes in stem roots were still lower (P = 0.05) than the control plots in plots treated with oxamyl and ethoprop alone and 1,3-D plus emulsifier, oxamyl, ethoprop, fenamiphos, and both rates of sodium tetrathiocarbonate with foliar applications (Table 2).

In experiment 2, treatments had no effect on bulb weight (P = 0.05) on either 31 August or at harvest (data not shown). There were no differences in the number of stem bulblets on 31 August, although at harvest stem bulblets were more numerous in the plots treated with 1,3-D plus emulsifier alone than in the control plots (P = 0.05; data not shown).

In experiment 3 on 9 and 22 September, numbers of lesion nematode in soil, bulb, and stem roots were lower (P = 0.05) than the control plots in those treated with drip-applied oxamyl (Table 3).

Discussion

Pratylenchus penetrans biology and control have been extensively studied because it is the most economically important plant-pathogenic nematode in the northeastern states (12). Because of its wide host range (7,12), nonchemical control measures such as crop rotation and use of resistant varieties have not generally been feasible methods of control. *Pratylenchus penetrans* is able to reproduce at temperatures as low as 9 C (12) and thus may be active most of the year in northern California bulb production areas (6). The nematode has been found statewide in California (18) and is of economic concern on ornamentals, apples, cherries, and strawberries (15). Studies on control of *P. penetrans* on bulb crops in California have been mostly on Easter lilies (5,10,11), on which the nematode was first recognized as a pest in 1946 (8). Chemical control techniques developed on Easter lilies have generally been used on oriental lilies as well.

Effective management of plant-parasitic nematodes requires control in both planting stock and soil. We tested a relatively new technique for application of nematicides to soil (2,13,16,17) with or without foliar applications of a systemic nematicide. Several of the chemicals tested (e.g., sodium tetrathiocarbonate, which releases carbon disulfide) were expected to control nematodes present in soil while others (e.g., oxamyl, fenamiphos) were expected to control nematodes within roots as well. The chemical application rates used in these experiments were generally less than would be used in conventional applications of the currently or previously registered chemicals: 1,3-D (374 liters/ha, 94% a.i.), metam–sodium (701–935 liters product/ha, 33% a.i.), methyl bromide (448–560 kg/ha), phorate (112–179 kg product/ha, 10% a.i.), chloropicrin (560 kg/ha),

TABLE 3. Effect of oxamyl treatments on densities of *Pratylenchus penetrans* in soil and roots (1988).

	Pratylenchus penetrans										
					Bulb				Stem		
	Soil (nematodes per liter)				(nematodes per g root)						
Treatment†	1 June	5 July	9 Sept	22 Sept	1 June	5 July	9 Sept	22 Sept	5 July	9 Sept	22 Sept
Oxamyl	175	75	25 *	25 *	27	47	3 *	6 *	7	2 *	4 *
Control	125	75	225	500	7	22	48	27	9	49	25

Data are means of four replications.
† Three treatments of 4.5 liters product/ha at monthly intervals beginning 23 May (100 ppm a.i. for 60 minutes).
* Mean significantly different from the control without foliar treatment at P = 0.05.
Analysis performed on $\log_{10}(X + 1)$ transformed data where X = the nematode count.

fenamiphos (67–134 kg/product/ha, 10% a.i.), or aldicarb (56–78 kg product/ha, 10% a.i.).

A single midseason drip irrigation application with or without three foliar oxamyl treatments (experiment 1) did not provide nematode control. However, the improved visual appearance of plants in the oxamyl-treated plots compared with the other treatments convinced the grower to switch from sprinkler to drip irrigation the following season to facilitate larger scale applications (experiment 3). It is likely that chemical applications controlled other root-feeding organisms that were not monitored in the experiments. For example, in late August, symphyllids (Chilopoda) were abundant in the plot area. Such organisms were more likely to have been killed by oxamyl or ethoprop than by 1,3-D or sodium tetrathiocarbonate because of the rates used and possible chemical persistence.

Multiple drip irrigation applications begun earlier in the growing season (experiments 2 and 3) provided better nematode control. Visual ratings were not taken in 1988 because plant growth appeared similar in all plots. Lesion nematode populations were reduced relative to controls in soil or roots on one or more sampling dates by all drip-applied treatments except the plant extracts. On some sampling dates, additional reductions occurred in plots treated with foliar applications of oxamyl. Foliar applications of oxamyl alone also reduced lesion nematodes in soil or roots. Water extracts of marigolds are nematicidal and in some cases phytotoxic to established crops (14). Nematode control might not have been achieved in our experiments because sufficient material was only available for two applications of the plant extracts versus four applications for the other chemicals.

We expressed application rates in a traditional manner (liter/ha/application) and in a nontraditional one (ppm a.i. in water applied over a period of time), which is more accurate for describing applications via drip irrigation systems. The length of time over which the per hectare rate is applied can effect the results achieved (Radewald and Westerdahl, unpubl.). Several types of applicators with distinct attributes that affect the consistency of the application are available for adding chemicals to drip irrigation systems. Positive placement injectors (such as the motor-driven syringe applicator and piston pump used in our experiments) maintain a constant level of chemical concentration (ppm in water) in the drip irrigation line during the entire application period (16). Differential-pressure injection systems divert a portion of the water flow from the main line into a container of chemical, which is gradually diluted and displaced into the main water flow. Thus, a very concentrated solution (i.e., several thousand ppm in water) is injected at the beginning of an application and a very dilute solution is injected at the end (16). This type of application equipment is more likely to result in phytotoxicity on established crops and may reduce the exposure time of the target organism to the required concentration for the length of time required for control. A venturi injector, the third type of commonly used injection apparatus, sucks the chemical from a tank into the irrigation line and produces a concentration somewhere in between the other two methods (16).

Emitter spacing can also affect the results of nematicide application. If emitters are too widely spaced for a given crop, adequate coverage of the root zone may not be achieved (2). On the other hand, emitters spaced too closely together may reduce nematode control. For example, diminished nematode control followed multiple applications of nematicides within 2 years in grape vineyards when emitters were spaced 60 cm apart or less (13). Emitter spacings greater than 30 cm were not feasible in the current studies because the wetting pattern would not have touched the root zone of all plants within the row. The availability of several materials with different modes of action and that could be rotated might minimize the rate at which loss of control occurs.

In addition to the possible presence of other pathogens, the variability in control of *P. penetrans* among the experiments could have occurred for a variety of reasons; however, the environmental variability over the 2-year study period and the range of initial nematode population densities were typical of what a grower would encounter. Additional experiments beyond the scope of the present studies are needed to delineate the cause or causes of the differences observed.

For drip irrigation application of nematicides, the choice of application equipment, emitter spacing, nematicide, length of application, soil type, the timing and amount of irrigation before and after treatments, the depth of groundwater, the nematode pest, and the crop and its rooting depth must all be considered for a given treatment situation. Considerable knowledge of these factors has developed during the past decade, although much of it has not been published. With this background, for *P. penetrans* on a shallow rooted crop, in a shallow groundwater situation with a moderately heavy, constantly wet, high organic matter soil, we chose relatively short, constant rate treatments designed to wet only the root zone of the crop. We were successful in developing a new tool for growers on this crop but would not dispute that other application schemes might work as well or perhaps better.

Our experiments demonstrated that drip irrigation applications of several nematicides with or without foliar applications of oxamyl can reduce the level of *P. penetrans* infestation in oriental lily bulbs without phytotoxicity. Although drip application requires additional knowledge by growers compared with traditional application techniques, it could allow growers to use a broader spectrum of materials, combine two or more chemicals if necessary, and reduce the potential for various forms of environmental contamination.

The cost of a drip irrigation system is more than the cost of conventional application equipment. Part of the differential could be recovered by the use of smaller amounts of chemicals. Methods of accounting that utilize only the cost of chemicals, equipment, and application to evaluate a given control method may underestimate the costs of nematode management because they do not take into account the potential for groundwater contamination and the subsequent clean-up cost.

Literature Cited

1. Abacus Concepts. 1989. SuperANOVA. Berkeley, CA: Abacus Concepts, Inc.

2. Apt, W. J., and E. P. Caswell. 1988. Application of nematicides via drip irrigation. Supplement to the Journal of Nematology (Annals of Applied Nematology) 2:1–10.

3. Ayoub, S. M. 1977. Plant nematology: An agricultural training aid. Sacramento, CA: State of California Department of Food and Agriculture, Division of Plant Industry.

4. Byrd, D. W., K. R. Barker, H. Ferris, C. J. Nusbaum, W. E. Griffin, R. H. Small, and C. A. Stone. 1976. Two semi-automatic elutriators for extracting nematodes and certain fungi from soil. Journal of Nematology 8:206–212.

5. Hart, W. H., A. R. Maggenti, and J. V. Lenz. 1967. Bulb treatments for the control of root-lesion nematode, *Pratylenchus penetrans*, in Easter lily. Plant Disease Reporter 51:978–980.

6. Hawkins, L. S. 1991. IPM options for Easter lily bulb production: An overview. Sacramento, CA: California Department of Food and Agriculture. Environmental Monitoring and Pest Management Branch.

7. Jensen, H. J. 1953. Experimental greenhouse host range studies of two root-lesion nematodes, *Pratylenchus vulnus* and *Pratylenchus penetrans*. Plant Disease Reporter 37:384–387.

8. Jensen, H. J. 1966. Phosphate pesticides control root-lesion nematodes in Oregon Easter lily plantings. Plant Disease Reporter 50:923–927.

9. Koepsell, P. A., and J. W. Pscheidt. 1991. Pacific northwest plant disease control handbook. Corvallis, OR: Oregon State University.

10. Maggenti, A. R., W. H. Hart, and J. V. Lenz. 1967. Soil treatments for the control of root-lesion nematode (*Pratylenchus penetrans*) on Easter lily. Plant Disease Reporter 51:549–552.

11. Maggenti, A. R., W. H. Hart, and J. V. Lenz. 1970. Granular applications of phosphates and carbamates for control of *Pratylenchus penetrans* on Easter lily (*Lilium longiflorum* cv. Ace). Plant Disease Reporter 54:1012–1014.

12. Mai, W. F., J. R. Bloom, and T. A. Chen. 1977. Biology and ecology of the plant-parasitic nematode *Pratylenchus penetrans*. Bulletin 815, The Pennsylvania State University College of Agriculture Agricultural Experiment Station, University Park, Pennsylvania.

13. McKenry, M. V. 1985. Completion of studies

on nematicides and drippers. Raisin Research Reports. Fresno, CA: California Raisin Advisory Board.

14. McKenry, M. V. 1991. Marigolds and nematode management. Plant Protection Quarterly. University of California Kearney Plant Protection Group and the Statewide IPM Project 1:1–4.

15. McKenry, M. V., and P. A. Roberts. 1985. Phytonematology study guide. Publication 4045. Oakland, CA: Cooperative Extension University of California Division of Agriculture and Natural Resources.

16. Nakayama, F. S., and D. A. Bucks. Developments in agricultural engineering 9. Trickle irrigation for crop production design, operation and management. Amsterdam, The Netherlands: Elsevier.

17. Radewald, J. D., F. Shibuya, N. McRae, and E. G. Platzer. 1986. A simple, inexpensive, portable apparatus for injecting experimental chemicals in drip irrigation systems. Journal of Nematology 18: 423–425.

18. Siddiqui, I. A., S. A. Sher, and A. M. French. 1973. Distribution of plant parasitic nematodes in California. Sacramento, CA: State of California Department of Food and Agriculture, Division of Plant Industry.

19. Warner, S. 1985. Final report. Workplan for water quality management planning program (Section 205 (j)) on groundwater pollution by pesticides on the Smith River plains Del Norte County. Santa Rosa, CA: Water Quality Control Board, North Coast Region.

20. Westerdahl, B. B., D. Giraud, J. D. Radewald, and C. A. Anderson. 1991. Management of *Ditylenchus dipsaci* in daffodils with foliar applications of oxamyl. Supplement to the Journal of Nematology 23: 706–711.