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Management of *Ditylenchus dipsaci* in Daffodils with Foliar Applications of Oxamyl[1]

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Abstract: *Ditylenchus dipsaci* (Kühn) Filipjev is a serious pest of commercial daffodil (*Narcissus* sp.) in northern California. The control measures practiced by growers in recent years are postharvest treatment of planting bulbs for 3 hours in a 1% solution of formalin at 44 C combined with preplant soil fumigation with 1,3-dichloropropene and (or) at-planting applications of phorate. In field trials, several combinations of rates (1.12, 2.24, or 4.48 kg a.i./ha in 189 liters of water/ha) and timings (one, two, or three applications at weekly intervals) of foliar applications with oxamyl on three daffodil varieties (Fortune, Ice Folley, and King Alfred) were evaluated as alternatives. Several treatments reduced nematode levels in leaves and bulbs. Phytotoxicity was not observed at any rate or combination of treatments.

Key words: chemical control, daffodil, *Ditylenchus dipsaci*, foliar application, *Narcissus* sp., nematicide, nematode, nonfumigant nematicide, oxamyl, stem and bulb nematode.

The stem and bulb nematode *Ditylenchus dipsaci* (Kühn) Filipjev is a serious pest of commercial daffodil (*Narcissus* sp.) production in Humboldt and Del Norte counties of California. The climate is characterized by cool summers with coastal fog and mild winters. Average annual rainfall is 190 cm, mostly falling during October to March. Cool soil temperature, high water tables, and acidic soils contribute to the potential for groundwater contamination by pesticides in the area. Bulb plantings commonly are rotated with pasture grasses (33).

In recent years, the commercial daffodil industry has ceased growing bulbs for sale and has begun producing cut flowers. Flowers are harvested in January and February, the foliage dies back in June, bulbs are dug in July, and bulbs are stored and replanted during September and October. Bulbs may remain in this production cycle for many years.

Until recently, hot water–formalin dipping (7) was used to disinfest bulbs of migratory endoparasitic nematodes. Use of this technique has decreased in the past 3 years because of uncertainties in the registration of formalin and grower perception that hot water treatment results in deformed flowers. Also, the length of time required for dipping (3 hours) is impractical for treating large numbers of bulbs.

In addition to hot water–formalin treatment of bulbs, growers in the past used preplant fumigation with DD (1,3-dichloropropene [1,3-D] and 1,2-dichloropropane [1,2-D]) and (or) at-planting applications of aldicarb. After 1,2-D and aldicarb were found in groundwater in 1982, practices changed to hot water-formalin dipping and preplant fumigation with 1,3-D (Telone II) and (or) at-planting applications of fenamiphos (Nemacur; 33). In 1986, reports of fenamiphos several feet deep in the soil resulted in the manufacturer withdrawing registration for use on bulbs. Since that time, 1,3-D and phorate (Rampart) have been used for preplant nematode control.

Oxamyl has been tested for nematode control on several crops using soil and foliar application in greenhouse and field trials (1, 3, 5, 9–17, 19, 21–24, 26, 28, 30, 31, 34–37). Only a few studies have reported phytotoxicity (3, 23, 24). A number of trials have tested the efficacy of multiple foliar applications (3, 9, 13, 15, 19, 21, 23–26, 31, 36). In some cases, multiple appli-

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cations at weekly intervals provided improved control over a single application (15, 23–25).

Despite extensive experimentation, oxamyl is not widely used as a nematicide in California. Oxamyl is unique among nematicides in that it is registered for foliar application, which should reduce chances for groundwater contamination over applications of chemicals to soil. It could be an alternative, as well, to hot water–formalin dipping. This investigation was designed to determine the effectiveness of one to three foliar applications of oxamyl at three rates for *D. dipsaci* control in daffodils in northern California.

Materials and Methods

Three experiments were conducted over 2 years, each on a different variety of daffodil (Fortune, Ice Folley, or King Alfred). Plots were established in infested fields where stem and bulb nematode symptoms were evident, and infestations were confirmed by extraction of nematodes from leaves. Plant symptoms were the presence of distorted leaves with characteristic yellow swellings called spikkels, which can be felt when leaves are pulled through the fingers, and brown, scaly leaf rings when bulbs are cut in half (8). Plants were grown following standard grower cultural practices. These consisted of: (a) a preplant application of 20-20-20 fertilizer at a rate of 1,360 kg/ha; (b) the planting of 7,258 to 10,886 kg of bulbs per ha 5 to 10 cm deep in a single row in 0.92-m wide beds in September and October; (c) harvesting of ca 15 flowers/kg of bulbs in January and February; (d) and burning of the foliage after it has died down in June prior to harvest in July. Fields were not irrigated because of adequate rainfall. To assure worker health and safety, all treatments were initiated after the completion of flower harvest and before top desiccation.

For nematode extraction, a leaf sample consisting of four leaves randomly selected from each plot was cut into 2-mm pieces, weighed, and placed in an intermittent misting chamber for 72 hours (4). Each bulb sample consisted of 4 bulbs, and one-fourth of each bulb was cut into 6-mm pieces, weighed, and placed in a misting chamber for 72 hours. Extracted nematodes were identified, then counted using a stereoscopic microscope.

In each experiment, plots were 0.92 m wide by 3 m long, in a randomized complete block. The untreated controls in Experiments 1 and 2, however, had to be placed at one end of the block to minimize contamination from spray drift. Experiments 1 and 2 were conducted in 1987 on the varieties Fortune and Ice Folley, respectively. There were 10 treatments and 3 replicates; treatments consisted of an untreated control and the nine combinations of one, two, or three applications of oxamyl at 1.12, 2.24, or 4.48 kg a.i./ha in 189 liters/ha of water applied to leaves with a hand sprayer (Model 2001-A, 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. The pretreatment sample in the Fortune experiment consisted of 20 individual leaves randomly selected from the plot area. The pretreatment sample for the Ice Folley experiment consisted of four samples of five leaves each, randomly selected from the plot area. Oxamyl efficacy was determined by assessing nematode numbers in leaves and bulbs following chemical applications. Experiment 3, conducted in 1988 on the variety King Alfred, had the same 10 treatments replicated 4 times in a randomized complete block.

Spray dates were 5, 13, and 21 April 1987, and 28 February, 1 March, and 8 March 1988. Treatments consisting of one or two applications were conducted on the first, or on the first and second, spray dates, respectively, in each year. In 1987, nematode numbers in leaf samples were evaluated pretreatment and on 14, 22, and 28 April. Nematodes in the bulbs were evaluated following harvest on 20 May. In 1988, nematode numbers in leaves were evaluated pretreatment and on 17 March. Numbers in bulbs and bulb weights were evaluated following harvest on 10 July.

TABLE 1. Effect of multiple applications of oxamyl on levels of *Ditylenchus dipsaci* per leaf and per gram of bulb of Fortune daffodil.

Oxamyl rate (kg a.i./ha)	Number of applications	*Ditylenchus dipsaci* per leaf Week 1	Week 2	Week 3	*D. dipsaci* per g of bulb
0	0	640 a w	218 a w	77 abc xy	31 abc wxy
1.12	1	212 a w	47 a wx	1,234 a w	86 abc wxyz
1.12	2	22 ab wxy	220 a wx	10 bc yz	112 ab wx
1.12	3	28 ab wxy	27 a wx	0 c z	12 abc xyz
2.24	1	73 ab wxy	231 a wx	175 ab wx	86 a w
2.24	2	273 ab wxy	31 a wx	0 c z	2 bc yz
2.24	3	727 a wx	21 a wx	0 c z	0 c z
4.48	1	5 b y	3 a x	22 bc yz	35 abc wxy
4.48	2	25 ab xy	11 a x	5 c yz	10 abc xyz
4.48	3	18 ab wxy	3 a x	0 c z	19 abc xyz

Nematode counts were transformed by $\log_{10}(x + 1)$ prior to statistical analysis. Results presented are nontransformed means of three replications. Initial population density/leaf = 3,328 ± 1,610 SE. Means within a column followed by the same letter(s) are not significantly different according to LSD test, $P = 0.05$ (a–c) and $P = 0.10$ (w–z).

Results were subjected to analysis of variance followed by least significant difference ($P = 0.05$ and 0.10) testing and by linear regression analysis (27). Both the 0.05 and 0.10 probability levels are presented because it could be advantageous for a grower to use a chemical treatment even if only a 90% chance of success is likely. The only loss to a grower who has no other chemicals available is the cost of the application. To stabilize variances, the transformation to $\log_{10}(x + 1)$ was used for nematode counts prior to analysis.

Some observations were also made on the efficacy of the hot water–formalin dip. On four different occasions, hot water-formalin dipped and undipped bulbs from the growers' standard treatments were evaluated for presence of *D. dipsaci*, as a comparison to reductions in nematode populations following treatment with oxamyl.

RESULTS AND DISCUSSION

Significant ($P = 0.10$) reductions of nematode numbers in leaves and bulbs compared to untreated controls were observed following oxamyl applications (Tables 1, 2). In the trial conducted on Fortune, the greatest nematode reductions occurred in the leaves. Regressions with negative slopes significantly ($P = 0.10$) different from zero occurred over time in four treatments: (a) three applications at 4.48 kg a.i./ha ($y = 1.73 - 0.59x$, $r^2 = 0.74$, $P = 0.003$); (b) two applications at 2.24 kg a.i./ha ($y = 2.20 - 0.74x$, $r^2 = 0.37$, $P = 0.08$); (c) three applications at 2.24 kg a.i./ha ($y = 3.11 - 1.07x$, $r^2 = 0.56$, $P = 0.02$); and (d) three applications at 1.12 kg a.i./ha ($y = 1.93 - 0.63x$, $r^2 = 0.48$, $P = 0.04$), where y = number of nematodes in the leaves and x = time in weeks.

Increasing the number of applications at all three rates resulted in regressions with negative slopes significantly different from zero for the number of nematodes within leaves one week following the last applications (Table 1): (a) 1.12 kg a.i./ha ($y = 1.88 - 0.56x$, $r^2 = 0.27$, $P = 0.08$); (b) 2.24 kg a.i./ha ($y = 1.59 - 0.55x$, $r^2 = 0.39$, $P = 0.03$); and (c) 4.48 kg a.i./ha ($y = 1.13 - 0.38x$, $r^2 = 0.27$, $P = 0.08$), where y = number of nematodes within leaves and x = number of applications.

One week after the last applications, four treatments showed nematode reductions ($P = 0.10$) in the leaves compared to untreated controls (three applications at 1.12 kg a.i./ha; two and three applications at 2.24 kg a.i./ha; and three applications at 4.48 kg a.i./ha (Table 1). The lowest rate used in this trial, one application at 1.12 kg a.i./ha, appeared to significantly stimulate nematode reproduction ($P = 0.10$).

Increasing the number of applications produced a regression with a negative slope

TABLE 2. Effect of multiple applications of oxamyl on levels of *Ditylenchus dipsaci* per leaf and per gram of bulb of Ice Folley daffodil.

Oxamyl rate (kg a.i./ha)	Number of applications	*Ditylenchus dipsaci* per leaf Week 1	Week 2	Week 3	*D. dipsaci* per g of bulb
0	0	271 a x	2,574 a x	674 a x	313 a x
1.12	1	36 ab xy	779 a xy	7,277 a x	95 ab xy
1.12	2	6 ab yz	5,699 a xy	247 a x	125 ab xy
1.12	3	7 ab xy	2,180 a x	1,680 a x	302 ab x
2.24	1	253 ab xy	1,075 a xy	488 a x	142 ab xy
2.24	2	60 ab xy	78 a y	897 a x	137 ab xy
2.24	3	33 ab xy	265 a y	459 a x	47 bc yz
4.48	1	68 ab xy	409 a xy	3,204 a x	134 ab xy
4.48	2	8 b z	103 a xy	1,047 a x	41 abc y
4.48	3	110 a x	261 a xy	18 a x	5 c z

Nematode counts were transformed by $\log_{10}(x + 1)$ prior to statistical analysis. Results presented are nontransformed means of three replications. Initial population density/leaf = 294 ± 217 SE. Means within a column followed by the same letter(s) are not significantly different according to LSD test, $P = 0.05$ (a–c) and $P = 0.10$ (x–z).

significantly different from zero for the number of nematodes within bulbs (y) only at 2.24 kg a.i./ha ($y = 1.6 - 0.49x$, $r^2 = 0.45$, $P = 0.02$), where x = number of applications (Table 1). Numbers of *D. dipsaci* within the bulbs at harvest were lower ($P = 0.10$) than those in untreated plots for only one treatment (three applications at 2.24 kg a.i./ha).

For the trial on Ice Folley daffodils (Table 2), the only rate resulting in a regression with a negative slope significantly different from zero for number of nematodes in the leaves (y) over time was 4.48 kg a.i./ha ($y = 2.68 - 0.53x$, $r^2 = 0.34$, $P = 0.10$), where x = time in weeks.

For Ice Folley, increasing the number of applications (Table 2) resulted in negative regressions with slopes significantly different from zero for the number of nematodes within bulbs (y) at two rates: 2.24 kg a.i./ha ($y = 2.34 - 0.31x$, $r^2 = 0.29$, $P = 0.07$) and 4.48 kg a.i./ha ($y = 2.44 - 0.54x$, $r^2 = 0.73$, $P = 0.004$), where x = number of applications. Within the bulbs at harvest, three treatments (three applications at 2.24 kg a.i./ha, and two or three applications at 4.48 kg a.i./ha) were lower ($P = 0.10$) than the untreated control.

Unlike the two previous trials, for the third trial conducted on King Alfred (Table 3), increasing the number of applications did not result in regressions with negative slopes significantly different from zero at any of the three rates used, for the number of nematodes within either the leaves or the bulbs. Grouping the data with respect to the total amount of oxamyl applied during all applications (0, 1.12, 2.24, 3.36, 4.48, 6.72, 8.96, or 13.44 kg a.i./ha) did result in a regression with a negative slope significantly different from zero for the number of nematodes within bulbs ($y = 1.86 - 0.07x$, $r^2 = 0.12$, $P = 0.03$), where x = application rate. Only one treatment

TABLE 3. Effect of multiple applications of oxamyl on levels of *Ditylenchus dipsaci* per leaf and per gram of bulb, and on bulb weight in grams of King Alfred daffodil.

Oxamyl rate (kg a.i./ha)	Number of applications	*Ditylenchus dipsaci* per leaf	*D. dipsaci* per g of bulb	Bulb weight (g)
0	0	5 a x	85 abc xy	33 b y
1.12	1	3 a x	91 abc xy	50 a x
1.12	2	0 a x	141 ab xy	43 ab xy
1.12	3	2 a x	59 abc yz	44 ab xy
2.24	1	228 a x	95 abc xy	36 ab y
2.24	2	12 a x	286 a x	36 ab y
2.24	3	4 a x	53 abc xyz	42 ab xy
4.48	1	63 a x	90 bc yz	40 ab xy
4.48	2	0 a x	7 c z	41 ab xy
4.48	3	2 a x	76 bc yz	45 ab xy

Nematode counts were transformed by $\log_{10}(x + 1)$ prior to statistical analysis. Results presented are nontransformed means of four replications. Means within a column followed by the same letter(s) are not significantly different according to LSD test, $P = 0.05$ (a–c) and $P = 0.10$ (x–z).

(two applications at 4.48 kg a.i./ha) showed a significant reduction ($P = 0.10$) of nematodes within bulbs. There were no significant ($P = 0.10$) reductions in the number of nematodes in leaves.

In four samples of bulbs that the grower had hot water–formalin dipped prior to planting, 0.04, 0.07, 25.60, and 0.20 nematodes/g of bulb were recovered. By comparison, 338.5, 663.0, 179.3, and 562.3 nematodes/g of bulb were recovered from four samples from the same batch of planting stock that had been hot water–formalin dipped.

Some nematicidal compounds also have fungicidal and insecticidal properties. A complex of soil fungi, including *Rhizopus* sp., *Penicillium* sp., *Fusarium* sp., *Mucor* sp., *Geotrichum* sp., and *Trichoderma* sp., have been isolated from within the planting stock used by daffodil growers in California (unpubl. data). It is probable that these or other fungi, as well as bacteria, are not killed by oxamyl, therefore contributing to the damage observed in bulbs. They are, however, killed or greatly reduced by formalin in the hot water dipping procedure. Additionally, symphylids and other soil-dwelling invertebrates capable of feeding on bulbs have been observed in growers' fields.

The variability in control among the three experiments could have occurred for a variety of reasons, including: (a) differences due to varieties, (b) variability in initial nematode population densities, (c) climatic differences such as rainfall or temperature, or (d) physiological differences in the host plants or nematodes at different times of the growing season. The environmental variability over the 2-year period during which the experiments were conducted and the range of initial nematode population densities are typical of what a grower contemplating use of foliar applications of oxamyl would encounter. Additional experiments beyond the scope of the present studies would be needed to delineate the cause or causes of the differences observed.

This study demonstrates that foliar applications of oxamyl can reduce the level of nematode infestation in daffodil bulbs without phytotoxicity. However, foliar applications of oxamyl at the rates tested do not provide the degree of control of nematodes and other organisms that has been provided by hot water–formalin dipping. Foliar applications of oxamyl are currently being used by growers under a Special Local Need (Section 24[c]) registration to reduce nematode levels in bulbs during lapses in the registration for the usage of formalin, and where infestations in new plantings arise from overwintering infested bulbs.

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