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Cyperus Tubers Protect *Meloidogyne incognita* from 1,3-Dichloropropene[1]

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Abstract: *Meloidogyne incognita*-infected and noninfected tubers of yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*Cyperus rotundus*) were treated with 56 L/ha 1,3-dichloropropene (1,3-D) in microplots and subsequently examined for tuber and nematode viability in the greenhouse using a chile pepper (*Capsicum annuum*) bioassay system. The study was conducted three times. Nutsedge tuber viability and *M. incognita* harbored in both yellow and purple nutsedge tubers were unaffected by 1,3-D treatment. Nematode reproduction on nutsedges and associated chile pepper plants varied among years, possibly due to differing levels of tuber infection or soil temperature, but was not affected by fumigation. The presence of *M. incognita* resulted in greater yellow nutsedge tuber germination and reproduction. The efficacy of 1,3-D for management of *M. incognita* in chile pepper production is likely to be reduced when nutsedges are present in high numbers, reinforcing the importance of managing these weeds and nematodes simultaneously.

Key words: *Capsicum annuum,* chile pepper, *Cyperus esculentus, Cyperus rotundus,* 1,3-dichloropropene, fumigant, management, *Meloidogyne incognita,* nematicide, perennial weed, purple nutsedge, root-knot nematode, tuber, yellow nutsedge.

Chile pepper (*Capsicum annuum* L.) is a $47 million commodity and the leading source of row crop income in New Mexico (Nelson and Hand, 2001). Chile pepper is produced under intensive management in fields that are rarely left fallow through a growing season. The southern root-knot nematode (*Meloidogyne incognita*) is a severe pathogen of chile pepper and all the rotational crops grown in the state. Chile pepper is extremely sensitive to root-knot nematode injury, with yield reductions often exceeding 40% (Di Vito et al., 1992; Lindsey and Clayschulte, 1982; Thies et al., 1997; Thomas et al., 1995). Preplant population densities as low as 12 eggs and juveniles/500 cm^3 soil can reduce chile yields in some commercial cultivars (Thomas et al., 1995). In addition to yield reduction, plant stunting associated with *M. incognita* infection reduces crop canopy closure in chile pepper and many rotation crops, thereby enhancing weed problems.

Yellow and purple nutsedge (*Cyperus esculentus* and *C. rotundus*) are major weed pests of chile pepper because of slow crop growth that results in an open crop canopy, limited nutsedge control alternatives in chile pepper or rotational crops, and intensive use of irrigated lands. In sandy soils where stunting due to *M. incognita* is most severe, yellow and purple nutsedge are frequent problem weeds. Both yellow and purple nutsedge are hosts of *M. incognita* (Bird and Hogger, 1973; Schroeder et al., 1993, 1994). *Meloidogyne incognita* has been recovered from 85% of the nutsedge plants sampled in a survey of 40 root-knot infested chile pepper fields in southern New Mexico (Thomas and Schroeder, unpubl. data).

In greenhouse experiments, *M. incognita* inoculum levels 200-fold greater than those found to be pathogenic to chile pepper exhibited no pathogenicity on either yellow or purple nutsedge (Schroeder et al., 1999). In this and other greenhouse and field experiments, nutsedge tuber numbers and weights were often higher in the presence of *M. incognita* (Schroeder et al., 1994, 1999). Tubers, the main propagative units of both nutsedge species, harbor *M. incognita,* providing an overwintering site for the nematodes and a source of inoculum for chile pepper or other susceptible crops (Hogger and Bird, 1976; Schroeder et al., 1994). During the winter months, recovery of root-knot nematode eggs from purple nutsedge roots, rhizomes, and tubers persisted at a relatively constant level in the field despite the absence of chile pepper plants (Thomas and Schroeder, unpubl. data).

The principal fumigant nematicide used in southern New Mexico is 1,3-dichloropropene (1,3-D) due to its broad registration in vegetable crops and compatibility with the cool spring soil temperatures in the region. Under field conditions, 1,3-D suppressed *M. incognita* population development in chile pepper for 90 days, enhancing both yield and fruit quality (Thomas, 1994). At high application rates, this pesticide may reduce populations of certain perennial weeds such as Canada thistle and bindweed (Anonymous, 1994). However, 1,3-D is expected to have limited herbicidal activity on nutsedge tubers at the rates and method of application used in this region. When methyl bromide, which effectively controls both nutsedges and nematodes, is no longer available, 1,3-D is one of the obvious pesticide alternatives for use in vegetable crops that are infested with root-knot nematodes. We hypothesized that since nutsedge tubers harbor *M. incognita,* the tubers may protect nematodes from 1,3-D and enhance subsequent inoculum levels resulting in greater early-season infection of chile pepper. The objectives of this research were to determine if fumigation with 1,3-D reduced the

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rate of secondary infection of chile pepper by *M. incognita* harbored in yellow and purple nutsedge tubers and if fumigation affected tuber viability.

Materials and Methods

Experiments were conducted in two phases each year during 1997, 1998, and 1999. In the first phase, *M. incognita*-infected or noninfected yellow nutsedge (*Cyperus esculentus* L.) tubers and purple nutsedge (*Cyperus rotundus* L.) tubers were planted in field microplots in early February. Later that month half of the plots were fumigated with 1,3-D. In the second phase, tubers were removed from the microplots and transferred to the greenhouse where germination was assessed and tubers were bioassayed for the presence of *M. incognita*.

The overall experimental design was a split-split plot in a completely randomized design with four replications. The whole plot treatment was application or no application of 1,3-D with whole plot experimental units being pairs of microplots. The split plot factor (randomized to one microplot in each pair) was presence or absence of *M. incognita* in the nutsedge cultures that were the sources of tubers for each experiment. Because each microplot contained both nutsedge species, the split-split plot factor was nutsedge species. Data were analyzed by analysis of variance separately by year using the general linear models procedure of SAS (SAS Institute, Inc., Cary, NC) because of differences in *M. incognita* infection rates and environmental conditions among years. Least squares means and standard errors are reported, along with observed significance levels for F-tests. Because all main-effect factors were at two levels only, no post-hoc tests were performed.

Microplot phase: Studies were initiated in 76-cm-diam. microplots containing an Anthony-Vinton fine sandy loam soil (76% sand, 11% silt, 13% clay; 0.8% organic matter, pH 7.7) at the Leyendecker Plant Science Research Center, Doña Ana County, New Mexico, in February each year. Each of the eight pairs of microplots consisted of one *M. incognita*-infested and one noninfested plot. The soil in the top 30 cm of each microplot was mixed with a shovel, leveled, irrigated, and allowed to settle prior to planting and fumigation each year.

In 1997 and 1998, yellow nutsedge tubers and purple nutsedge tubers were gathered separately from *M. incognita*-infested and noninfested microplots that had been planted with the respective nutsedge species plus chile pepper (*Capsicum annuum* cv. NM 6-4) the previous season. Earlier work had shown that *M. incognita* populations on nutsedges were higher when chile pepper was associated with the weed (Schroeder et al., 1993). Prior to establishing the experiment in 1999, yellow nutsedge and purple nutsedge tubers were obtained from *M. incognita*-infested and noninfested greenhouse cultures in late January, placed in small cans filled with a twice-pasteurized 2:1 mixture by volume of sand and Anthony-Vinton fine sandy loam, and buried in the microplots for 2 weeks to simulate temperature conditions in the field. Mean fresh weights of tubers each year ranged from 0.02 g to 0.18 g and 0.1 g to 1.12 g for yellow and purple nutsedge, respectively. No egg masses or other indications of the presence of *M. incognita* were observed in nutsedge tubers from nematode-infested cultures, so the rate of infection among tubers could not be assessed prior to initiating each experiment.

Yellow nutsedge and purple nutsedge tubers were separated by species and placed in nylon mesh bags (six tubers per bag). Four bags of tubers of each species were paired with bags from the other species and buried 20 cm deep, 20 cm apart, and 20 cm from the edge in each microplot between late January and mid-February of each year (Table 1). *Meloidogyne incognita*-infected tubers were buried in root-knot-infested plots, and noninfected tubers were buried in noninfested plots. After the tubers were planted, the soil was leveled, tamped with a rake, and sprinkled with 5.7 liters of water/plot. One to 2 weeks later (mid- to-late February Table 1), four of the microplot pairs were fumigated with 56 liters/ha 1,3-dichloropropene applied 30.5 cm deep at five injection points spaced 25 cm apart and 12.5 cm inside the circumference of each plot. This application rate is typical for commercially produced peppers in New Mexico, where the standard spacing between rows is 102 cm. Immediately after application,

Table 1. Experimental conditions during evaluation of 1,3-dichloropropene efficacy against *Meloidogyne incognita* in yellow and purple nutsedge tubers.[a]

	Year		
	1997	1998	1999
Mircoplot phase			
Treatment date			
Tuber insertion	19 Feb.	29 Jan.	9 Feb.
1,3-D application	25 Feb.	16 Feb.	16 Feb.
Tuber removal	19 Mar.	5 Mar.	9 Mar.
Environmental condition			
Soil temperature (°C)[b]	15	10	14
Range (°C)	8.2–18.8	8.0–12.6	5.9–17.1
Days > 10 °C[c]	26	12	24
Cumulative precipitation (mm)	4.8	9.9	0
Greenhouse phase			
Environmental condition			
Air temperature (°C)	26	28	26
Soil temperature (°C)[d]	25	26	27
Cumulative PAR (W/m^2)[e]	31,335	29,076	27,299

[a] Environmental conditions were recorded hourly and averaged over the duration of each experiment except for soil temperature ranges in the microplot phase, which were averaged daily.

[b] Soil temperatures are the average of three probes inserted 15 cm deep in microplots.

[c] Number of days between tuber insertion and removal when average soil temperature exceeded the 10 °C threshold for *M. incognita* development.

[d] Soil temperatures are the average of two probes inserted 10 cm deep in pots.

[e] Summation of the photosynthetically active radiation (PAR) accumulated during each greenhouse study.

the soil in each plot was tamped heavily with a rake and sprinkled with 2 liters of water to help seal in the fumigant. Air temperature, soil temperature (15-cm depth), and precipitation in the microplots were monitored throughout the first phase of the experiment using a Campbell CR-10 Measurement and Control Module (Campbell Scientific, Logan, UT; Table 1). After the fumigant had dissipated, the tubers from each microplot were removed, divided into two groups of 12 tubers/species, and planted in the greenhouse as described later.

Greenhouse phase - chile pepper bioassay: The soil used in the greenhouse phase of the experiments was a 2:1 mixture by volume of sand and the Anthony-Vinton fine sandy loam soil found in the microplots. The soil mixture (85% sand, 10% silt, 5% clay; 0.2% organic matter; pH 7.7) was pasteurized twice at 75 °C prior to potting. In early to mid-February each year 'NM 6-4' chile peppers were planted in 15-cm-diam. (1997 and 1998) or 20-cm-diam. (1999) pots and thinned to 1 plant/pot. The pepper plants were at the two-leaf stage of growth when the yellow nutsedge and purple nutsedge tubers were removed from the microplots each year. Twelve tubers from each nutsedge species in each microplot were divided between two pots containing pepper plants (6 tubers/pot), and grown for approximately 75 days to bioassay for the presence of *M. incognita*. The pots containing chile pepper plus yellow nutsedge were blocked separately from pots containing chile pepper plus purple nutsedge due to space limitations. Microplot replications were assigned to greenhouse blocks within each nutsedge species. Plants were watered and fertilized as needed throughout each experiment.

At harvest, nutsedge and chile pepper shoots were removed at soil level. Below-ground structures including pepper roots and nutsedge roots, rhizomes, and tubers were rinsed clean of soil and separated by species. *Meloidogyne incognita* eggs were extracted separately from the pepper roots and from the combined nutsedge roots, rhizomes, and tubers using 0.5% NaOCl (Hussey and Barker, 1973). Following egg extraction, nutsedge tubers were removed from roots and rhizomes and weighed separately. Data from pepper plants included root and shoot dry weights and *M. incognita* eggs per gram dry root. Nutsedge data included shoot, tuber, and combined root plus rhizome dry weights, tuber number, and *M. incognita* eggs per gram root plus rhizome dry weight. The pattern of statistical significance was the same between log-transformed and non-transformed nematode egg count data, so only the results of statistical analyses using non-transformed data are presented.

Greenhouse phase - nutsedge germination: The remaining 12 yellow nutsedge or purple nutsedge tubers from each microplot were planted in individual 15-cm-diam. pots per species containing the previously described pasteurized sand:soil mixture. Pots from both nutsedge species were placed on one greenhouse bench and blocked according to microplot replication. Nutsedges were harvested 21 days after planting to determine the number of original tubers that germinated and the number of secondary tubers that were produced.

Environmental conditions in the greenhouse were monitored using a Campbell CR-10 Measurement and Control Module (Campbell Scientific, Logan, UT; Table 1). In 1997 and 1998, all pots were placed on heated benches maintained at 28 °C after nutsedge tubers were planted. After determining that greenhouse soil temperatures in pots outside heat benches remained above 25 °C during the experimental periods in 1997 and 1998, no heat benches were used in 1999.

Results

Average soil temperatures were similar during periods of nutsedge tuber exposure to 1,3-D in 1997 and 1999 (14 °C to 15 °C) but nearly 4 °C to 5 °C cooler in 1998 (Table 1). Average daily soil temperatures always exceeded the 4.4 °C minimum for 1,3-D efficacy during exposure periods each year. Average daily soil temperatures exceeded 10 °C less than half as frequently (12 fewer days) in 1998 as in 1997 or 1999. Total precipitation was minimal throughout the exposure periods in all 3 years. Soil temperatures during the greenhouse experiments averaged 26 ± 1.0 °C in all 3 years.

Overall, there were few differences due to 1,3-D treatment in *M. incognita* reproduction; chile pepper root growth; or nutsedge germination, root plus rhizome growth, and secondary tuber production in any year of the study. In 1997, none of the purple nutsedge tubers collected from noninfested microplots germinated in either the pepper bioassay or nutsedge germination study. Therefore, the noninfested purple nutsedge treatment combination was excluded from the analysis of the 1997 data, and two sub-analyses were used to compare responses from *M. incognita*-infected and noninfected yellow nutsedge tubers and responses between *M. incognita*-infected yellow and purple nutsedge tubers.

Chile pepper bioassay study: Chile pepper became infected with *M. incognita* from yellow nutsedge and purple nutsedge tubers in all 3 years of the study (Table 2). The incidence of *M. incognita* reproduction ranged from 13% of pepper plants bioassayed with nontreated tubers in 1998 to 94% of all pepper plants bioassayed in 1999, regardless of 1,3-D treatment. Nematode reproduction was low on both chile pepper and nutsedges in 1998, regardless of fumigation. In all 3 years, treatment of nutsedge tubers with 1,3-D had no effect on the number of *M. incognita* eggs per gram dry root produced on associated chile pepper plants used in the bioassay. In general, *M. incognita* reproduction was greater on chile pepper grown with purple nutsedge than with yellow

TABLE 2. 1,3-Dichloropropene main-effect means for *Meloidogyne incognita* reproduction on chile pepper bioassay plants and nutsedges after tuber fumigation.[a]

Year and 1,3-D treatment	Eggs/g dry root		Incidence of reproduction (%)[b]		
	Chile pepper	Nutsedge	Chile pepper	Yellow nutsedge	Purple nutsedge
1997					
56 liters/ha[c]	4,527	9	23	13	38
Untreated	11,170	287	44	0	75
P > F	0.3001	0.1193			
SE	4,142	111			
1998					
56 liters/ha[c]	36	7	38	25	63
Untreated	8	7	13	38	88
P > F	0.1513	0.9847			
SE	12	3			
1999					
56 liters/ha[c]	596	51	94	75	88
Untreated	490	78	94	63	75
P > F	0.7920	0.6216			
SE	271	36			

[a] Data are main plot means of 16 pots containing nutsedge tubers from *M. incognita*-infested sources. For bioassay purposes, each pot contained one pepper plant and six nutsedge tubers.
[b] Percentage of pots from which *M. incognita* eggs were recovered from pepper or nutsedge root systems.
[c] Nutsedge tubers were buried in microplots and treated with 1,3-D prior to each bioassay.

nutsedge (Table 3). Numbers of *M. incognita* per gram of chile pepper root were greater (P = 0.04) in the presence of purple than yellow nutsedge in 1997 and in 1999 (P = 0.06) but were not affected by nutsedge species in 1998 (P = 0.57). Nematode reproduction was 179 and 15 times greater for chile pepper grown with purple nutsedge than with yellow nutsedge in 1997 and 1999, respectively (Table 3).

As with chile pepper, *M. incognita* reproduction occurred on both purple nutsedge and yellow nutsedge in all 3 years. In general, reproduction was lower on nutsedge than on chile pepper (Table 2) and greater on purple than on yellow nutsedge (Table 3). Treatment of tubers with 1,3-D failed to reduce *M. incognita* reproduction on nutsedge following germination. The incidence of reproduction on yellow nutsedge ranged from lows of 0% and 13% for pots containing nontreated and fumigated tubers, respectively, in 1997 to highs of 75% and 63% for pots containing nontreated and fumigated tubers in 1999 (Table 2). The incidence of reproduction on purple nutsedge was more consistent among years, ranging from a low of 38% for pots containing 1,3-D treated tubers in 1997 to a high of 88% for nontreated tubers in 1998 and fumigated tubers in 1999. More *M. incognita* eggs per gram dry root plus rhizome were produced on purple nutsedge than yellow nutsedge in 1998 (Table 3).

Nutsedge germination study: Overall, 1,3-D had no effect on either yellow or purple nutsedge tuber germination (Table 4). No significant interactions affecting nutsedge germination were found between 1,3-D and the two nutsedge species or *M. incognita* in 1997 or 1999. In 1998, however, an interaction was observed between 1,3-D and nutsedge species (P = 0.001), where fumigation decreased yellow nutsedge tuber germination from 92% to 79% and increased purple nutsedge germination from 92% to 98% (SE = 2.2). A 1,3-D by *M. incognita* interaction was observed (P = 0.02) in 1998, with 1,3-D reducing nutsedge germination from 94% to 84% in the absence of *M. incognita* but increasing germination from 90% to 93% in the presence of *M. incognita* (SE = 2.1).

In 1997, yellow nutsedge germination was greater (P = 0.005) from *M. incognita*-infected tubers than from noninfected tubers (Table 4). The effect of *M. incognita* on purple nutsedge germination could not be determined because the noninfected tubers did not germinate that year. In 1998, purple nutsedge germination decreased from 99% to 92% when *M. incognita* was present, but yellow nutsedge germination increased from 79% in noninfected tubers to 92% for infected tubers (nutsedge by *M. incognita* interaction significant at P = 0.001, SE = 1.6). In 1999, yellow nutsedge germination was greater overall than purple nutsedge germination. The 1,3-D had no effect on the number of secondary tubers produced by fumigated yellow or purple nutsedge tubers (Table 4). In 1997, *M. incognita*-infected yellow nutsedge produced more (P = 0.01) secondary tubers than noninfected plants. Nematode infection had no effect on secondary tuber production in 1998, but in 1999 there was an interaction (P = 0.02) between presence or absence of *M. incognita* and nutsedge species regarding secondary tuber production. More tubers were produced from *M. incognita*-infected yellow nutsedge tubers, which yielded an average of 15 ± 0.6 secondary tubers compared to an average of

TABLE 3. Nutsedge species main-effect means for *Meloidogyne incognita* reproduction on chile pepper bioassay plants and nutsedges after tuber fumigation with 1,3-dichloropropene.[a]

Year and nutsedge species	Eggs/g dry root	
	Pepper	Nutsedge
1997		
Yellow nutsedge	87	1
Purple nutsedge	15,609	296
P > F	0.04	0.10
SE	4,203	111
1998		
Yellow nutsedge	29	1
Purple nutsedge	16	14
P > F	0.57	0.04
SE	16	3
1999		
Yellow nutsedge	66	16
Purple nutsedge	1,020	112
P > F	0.06	0.14
SE	297	40

[a] Data are subplot means of 16 pots average over whole plots (1,3-D treatment) using nutsedge tubers from *M. incognita*-infested sources. For bioassay purposes, each pot contained one chile pepper plant and six nutsedge tubers.

TABLE 4. Main-effect means for 1,3-dichloropropene, *Meloidogyne incognita,* and nutsedge species as factors for nutsedge tuber germination and secondary tuber production.[a]

	Germination (%)			Secondary tuber production		
Factor[b]	1997	1998[c]	1999	1997	1998	1999[d]
1,3-D						
Untreated	79	92	89	20	20	9
56 liters/ha	71	89	88	19	18	8
$P > F$	0.24	0.32	0.61	0.69	0.30	0.28
SE	4.5	2.0	2.0	2	1	1
M. incognita						
Noninfected	59	89	89	14	19	8
Infected	91	91	88	26	19	9
$P > F$	0.005	0.36	0.69	0.01	0.90	0.33
SE	5.0	1.5	2.7	2	1	1
Nutsedge species						
Yellow	91	85	95	26	31	13
Purple	58	95	81	9	6	3
$P > F$	0.0001	0.001	0.005	0.0001	0.0001	0.0001
SE	2.4	1.6	2.9	1	2	1

[a] Data are means of 16 pots and 12 nutsedge tubers per pot in greenhouse experiments. Due to lack of germination in noninfected purple nutsedge tubers in 1997, only data from *M. incognita* infected tubers were analyzed for 1,3-D and nutsedge effects in 1997; only yellow nutsedge data were analyzed for *M. incognita* effects in 1997.

[b] Source and treatment of nutsedge tubers prior to evaluation in the greenhouse.

[c] In 1998 interactions were observed between 1,3-D treatment and *M. incognita* ($P = 0.0240$), 1,3-D treatment and nutsedge species ($P = 0.0011$), and nutsedge species and *M. incognita* ($P = 0.0005$).

[d] In 1999 an interaction was observed between nutsedge species and *M. incognita* ($P = 0.0175$).

12 ± 0.6 tubers in noninfected yellow nutsedge plants. In contrast, the presence or absence of *M. incognita* had no effect on secondary tuber production by purple nutsedge, where tuber production averaged 3 ± 0.6 after 21 days. Secondary tuber production by yellow nutsedge was always greater than by purple nutsedge.

DISCUSSION

Under field conditions in New Mexico, *M. incognita* populations in chile pepper were suppressed for 90 days by 1,3-D, resulting in enhanced yield and fruit quality (Thomas, 1994). However, the results of the current study demonstrated that *M. incognita* harbored in yellow or purple nutsedge tubers was not controlled by the application of 1,3-D, resulting in subsequent reproduction on emerging nutsedges and associated pepper plants. Previous studies have shown that nutsedge tubers provide an overwintering site for *M. incognita* and can transmit this nematode to associated crop plants (Hogger and Bird, 1976; Schroeder et al., 1994; White et al., 2000). Chile peppers are seeded into previously irrigated, raised beds that must remain undisturbed until germination to preserve soil moisture. Nutsedges emerge weeks before the crop and grow vigorously, unlike chile pepper that may require 3 or 4 weeks for the first true leaves to emerge after planting. If nutsedges are present, the first generation of *M. incognita* is likely to be produced on roots arising from infected tubers while pepper plants are seedlings, even after fumigation with 1,3-D. Increased incidence of early-season nematode infection results in greater damage to the crop (Di Vito et al., 1992; Lindsey and Clayshulte, 1982; Thomas et al., 1995).

Several factors may have contributed to the large year-to-year variation in *M. incognita* reproduction observed on nutsedges and associated chile pepper bioassay plants. Foremost is variability in the incidence of nematode infection among tubers. At the time of selection there was no means of determining which tubers produced in *M. incognita*-infested plots actually harbored nematodes, or the level of infection per tuber. Because the study focused on determining whether tubers protect nematodes from 1,3-D, six tubers were planted with each chile pepper bioassay plant to increase the likelihood that pots contained infected tubers. This resulted in nutsedge root and rhizome biomass that far exceeded that of chile pepper—and most likely limited pepper root growth and distribution within pots, also contributing to variation among years. The increase in chile pepper root growth that accompanied larger pot volumes in 1999 (data not presented) may be partially responsible for the higher incidence of nematode reproduction on chile pepper (94%) in the final year of the study. At present, *M. incognita* reproduction has been observed only on yellow and purple nutsedge roots, not on tubers or rhizomes (Mauk et al., 1999). Actual nematode reproduction per gram of nutsedge root from infected tubers also would be skewed due to dilution by the additional weight of rhizomes and all biomass produced by noninfected tubers.

Low levels of tuber infection were most likely responsible for the low incidence of *M. incognita* reproduction on yellow nutsedges in 1997 and 1998. Both the level and incidence of reproduction on yellow nutsedge varied greatly among years, whereas the incidence and level of reproduction on purple nutsedge were gener-

ally greater and more consistent over time. Yellow nutsedge has shown greater variability in *M. incognita* infection than purple nutsedge under controlled inoculum studies in the greenhouse (Schroeder et al., 1999). Overall, purple nutsedge tubers were responsible for much greater *M. incognita* reproduction on chile pepper than yellow nutsedge tubers.

Although soil temperatures always exceeded the minimum for 1,3-D efficacy, low temperatures while tubers were submerged in microplots in 1998 may have contributed to the low level of nematode reproduction observed on both chile pepper and nutsedges later in the greenhouse. Soil temperatures exceeded the 10 °C threshold necessary for *M. incognita* development (Vrain et al., 1978) only 32% of the time in 1998 compared to 93% and 86% of the time in 1997 and 1999, respectively. In addition, Vrain et al. (1978) reported that when temperatures dip below 10 °C, juveniles may require temperatures to exceed the threshold for a period of time before resuming development. If *M. incognita* initially reproduced on nutsedges, slowed development in 1998 may have delayed reproduction by the first and subsequent generation, thereby substantially reducing the final numbers of nematode eggs produced on nutsedges and chile pepper. It also should be noted that in 1998 and 1999 soil temperatures never exceeded the 18 °C activity threshold required for movement of *M. incognita* juveniles in soil or host invasion (Prot and Van Gundy, 1981; Roberts et al., 1981), making it infeasible for contamination to occur from nematode movement between tubers or from nematodes in soil that may have escaped the 1,3-D treatment.

The lack of suppression of yellow nutsedge and purple nutsedge tuber germination by 1,3-D was expected. Despite an earlier report that higher application rates of 1,3-D may reduce populations of certain deep-rooted perennial weeds such as bindweed and Canada thistle (Anonymous, 1994), there are no reports of nutsedge tuber control with 1,3-D at the rate and method of application used in these experiments. The similarity in nutsedge reproduction (as indicated by secondary tuber formation) between plants arising from fumigated and nonfumigated tubers indicates no reduction in plant vigor following exposure to 1,3-D. The presence of *M. incognita* appears to benefit yellow nutsedge, as is evident from increased germination compared to noninfected tubers in two of the three seasons. Similarly, yellow nutsedge reproduction increased when *M. incognita* was present, which agrees with results from previous studies (Schroeder et al., 1994, 1999).

In conclusion, our results indicate that the efficacy of 1,3-D for management of *M. incognita* in chile pepper is likely to be reduced when nutsedges are also present in high numbers. Nutsedge tubers that harbor and protect *M. incognita* are unaffected by fumigation and give rise to plants upon which the nematode can reproduce, likely resulting in higher nematode numbers and earlier inoculum pressure on associated crops. Additional work is under way to characterize the nature of the relationship between *M. incognita* and nutsedges, and to identify methods of managing these weeds and root-knot nematodes simultaneously.

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