Control of *Meloidogyne chitwoodi* in Commercially Grown Russet Burbank Potatoes

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ABSTRACT

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Efficacy of fumigant and nonfumigant nematicides alone and in combination for control of the Columbia root-knot nematode (*Meloidogyne chitwoodi*) was studied in a commercial Russet Burbank potato field. The soil-injected fumigant dichloropropene in combination with preplant ethoprop treatments significantly ($P = 0.05$) reduced tuber infection to commercially acceptable levels (≤3% nematode culls). The dichloropropene-aldicarb combination and sprinkler-irrigation-applied metam-sodium significantly reduced tuber infection, although percent culls was ≥10. Single ethoprop, multiple ethoprop, and ethoprop-aldicarb combination treatments were less effective, with ≥19% culls. Aldicarb alone and dichloropropene alone provided no significant ($P = 0.05$) nematode control, with ≥84% culls. All treatments except sidedress aldicarb significantly increased total yield and estimated dollar return.

The Columbia root-knot nematode (*Meloidogyne chitwoodi* Golden et al) is the predominant nematode pest of potato in the Pacific Northwest (7). Economic losses result from the reduction in tuber quality caused by internal spots and galled tubers. Fumigation with soil-injected dichloropropene or sprinkler-applied metam-sodium fumigants is widely used in the region to control *M. chitwoodi* damage to potato. Fumigation with these materials has occasionally failed to control nematode damage in commercial fields. In a 5-yr study, fumigant-nonfumigant nematicide treatments provided more consistent control of tuber damage in plots at Washington State University, Irrigated Agriculture Research and Extension Center (IAREC), Prosser (11). Additional research was needed to evaluate these nematicide treatments under the standard crop rotations and management constraints of commercial production. In 1984, field trials were established in a commercial potato field to evaluate the efficacy of fumigant and nonfumigant nematicides alone and in combination for control of *M. chitwoodi* populations and tuber damage. This paper reports the results of those studies.

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MATERIALS AND METHODS

Two nematicide trials were conducted under center-pivot irrigation: one consisted of soil-injected fumigants and nonfumigants and the other consisted of sprinkler-applied metam-sodium. The field, located east of Pasco, WA, on a sandy loam soil, contained a mean *M. chitwoodi* second-stage juvenile (J2) population of 1,123/250 cm^3 of soil. The 1982 potato crop was severely damaged by root-knot nematodes.

The soil-injected fumigant and nonfumigant nematicide trials were conducted in a 1-ha block midway between the center and perimeter of the field. The plot area was disked twice in the fall and twice in the spring and rototilled in the spring to encourage decomposition of corn residue from the 1983 crop before applying the nematicides. Plot design was a randomized complete block with six replicates. Contiguous plots were three rows wide (2.5 m) and 21.4 m long. Dichloropropene (Telone II) was injected with tractor-drawn chisels 20 cm deep on 22.5-cm centers; 172-L/ha (20-gal/acre) and 232-L/ha (27-gal/acre) applications were made on 26 March and 3 April, respectively. During that period, soil temperatures were 8 and 9 C at 15 and 60 cm, respectively, and soil moisture was 12.5% in the upper 30 cm. Plots were packed with a ring roller immediately after fumigation.

Two nonfumigant nematicides, ethoprop (Mocap) and aldicarb (Temik), were evaluated alone, in combinations, and in combination with dichloropropene. Two preplant ethoprop 6E treatments (6.5 and 9.7 kg a.i./ha) were applied as broadcast sprays in 1.5 L of water per 44 m^2 on 23 April and immediately incorporated by rototilling to 10–15 cm. Granular formulations of ethoprop 10G and aldicarb 15G were broadcast at 3.2 kg a.i./ha in a 20-cm band over the rows on 13 June, after plants had emerged. Aldicarb at 3.2 kg a.i./ha was also applied at this time in bands on both sides of the hill, 15 cm from plants and 8 cm deep. A complete treatment list is presented in Table 1.

Metam-sodium plots were established in the remainder of the field. Metam-sodium was applied in fall and spring between 21 and 23 November and 17 and 26 April, respectively, at 153 and 184 L a.i./ha. Fall soil temperatures were 5 and 7 C at 15 and 60 cm, respectively, and spring temperatures were 8 and 9 C. The chemical was injected into the mainline at the center pivot and applied in 2.5 cm of water in 2-ha wedge-shaped areas as the pivot traveled around the field. Within each wedge, 50–70 m from the field parameter, a plastic tarp (9 × 30 m) covered the area that served as an untreated control. Each treatment with a paired untreated control was replicated three times. The field was planted with potato seed pieces (*Solanum tuberosum* cv. Russet Burbank) on 3 May. Plants emerged on 29 May and irrigation began on 3 June. Plots were maintained with standard cultural practices throughout the season. Composite soil samples of 10 cores (2.5 × 30 cm) were collected from the center row of each plot on 26 March (before treatment), on 9 July, and on 13 October (after harvest). In metam-sodium plots, two composite samples of 10 cores were collected from the rows to be harvested within the tarped area and two samples were collected from the adjacent treated area. A 250-cm^3 soil subsample was processed by semiautomated elutriator and centrifugation to extract the nematodes (3). Surface soil samples (2.5 × 5 cm) were collected in dichloropropene plots on 2 May and bioassayed with Columbia tomato plants.

A 9-m section was harvested from the center row in dichloropropene and nonfumigant trials. In metam-sodium plots, four 9-m strips were harvested, two within the untreated area and two in the adjacent treated area five rows from the edge of the tarped area. A 20-tuber sample was collected for nematode evaluation at IAREC, and the remaining tubers were commercially evaluated by Chef Ready, Othello, WA. The 20 tubers were peeled and individually rated on a scale of 0–6, where 0 = no nematode infection, 1 = 1–3, 2 = 4–5, 3 = 6–9, 4 = 10+, 5 = 50+, and 6 = 100+ infection sites per tuber. Percent cull was based on the proportion of tubers with an infection index >3 in each sample. Chef Ready evaluated tubers according to their standards for processing potatoes. Total yield of tubers was broken down into three categories: 1) >284 g, 2) 113–284 g or >5 cm in diameter, and 3) <113 g or <5 cm. Processors only pay for tubers in categories 1 and 2. Payable tubers were lye-peeled and inspected for nematode infection. If more than 20% of the peeled surface displayed nematode infection, the tuber weight was deducted from the payable weight, as were rot, green tubers, and other culls. This system is based on the usable tuber after trimming and was less severe than the IAREC grading system. Gross return per hectare was calculated by multiplying payable metric tons by the 1984 price of $71.70/t.

RESULTS

The dichloropropene and dichloropropene plus nonfumigant treatments significantly ($P = 0.05$) reduced J2 populations compared with untreated controls in July and October (Table 1). Bioassays of dichloropropene-treated soils detected low nematode densities (mean of 5/250 cm^3 of soil). Single and split nonfumigant nematicide treatments did not significantly reduce populations at either date. J2 densities were high enough to reduce yield, as indicated by the untreated yield. All treatments, except sidedress aldicarb, significantly ($P = 0.05$) increased total yield over the untreated controls, and those that included fumigation ranked higher than the nonfumigant treatments. However, fumigants alone did not rank as high in payable yield as fumigant-nonfumigant combination treatments. Untreated and single aldicarb treatments produced significantly ($P = 0.05$) lower payable yields than all other treatments.

The Chef Ready percent infection and IAREC percent cull and infection indices displayed similar trends across treatments; however, the magnitude was higher with the more critical IAREC rating. Neither rate of dichloropropene alone effectively reduced percent cull and infection index. However, both rates of dichloropropene plus ethoprop gave excellent control based on these criteria: percent culls $\leqslant 3$ and infection index $\leqslant 0.1$. Dichloropropene plus aldicarb was less effective in reducing nematode infection, as were ethoprop at 9.7 kg a.i./ha, multiple ethoprop treatments, and ethoprop-aldicarb combinations. Aldicarb alone provided no significant ($P = 0.05$) nematode control regardless of application method. The payable yield was greatest with dichloropropene at 232 L a.i./ha plus ethoprop 6E at 6.5 kg a.i./ha. The other treatments that gave high total yields produced lower payable yields because of the increased dockage from cull tubers.

The metam-sodium fumigants applied in fall and spring effectively reduced J2 density in the soil on the July sampling date (Table 2). However, the nematode densities were significantly less than in the untreated plots at harvest only in the 184-L a.i./ha fall treatment. Nematode damage evaluated by the three criteria was significantly ($P = 0.05$) less in all treated than in untreated plots. Similarly, total yields and payable yields were at least 15.7 and 20.6 t/ha greater, respectively, in treated than in untreated plots. Percent infection was >10 with the IAREC rating system.

DISCUSSION

M. chitwoodi is an extremely aggressive pathogen on potato. Santo (9) determined the economic threshold of *M. chitwoodi* on potato to be less than one juvenile per 250 cm^3 of soil at planting. The mean pretreatment nematode density in these trials was 1,123 juveniles per 250 cm^3, well above the mean pretreatment density of 66/250 cm^3 in 1980–1984 nematicide trials in Washington (11). The impact of high populations on plant growth was well documented in this study by yields in untreated being 10 t/ha less than in the effective treatments.

M. chitwoodi is well adapted to penetrate roots and develop at soil temperatures that occur in early spring (8). During 1984 at the Pasco field, J2 density in the soil increased as temperatures rose before planting, and roots were infected by plant emergence. J2 populations declined to the lowest annual density in early July before first-generation eggs hatched. J2 density increased rapidly from mid-July through August, with initial tuber invasion in late July, 70–80 days after planting.

Table 1. Nematode population densities, potato yields, tuber infection, and estimated net return from *Meloidogyne Chitwoodi* plots in 1984 soil-injected fumigant and nonfumigant trials[t]

Treatment and rate[u] (a.i./ha)	*M. chitwoodi* juveniles/ 250 cm^3 of soil			Percent infection[v]	Percent cull[w]	Infection Index[x]	Yield (t/ha)		Estimated net return[z] ($)
	Mar.	Jul.	Oct.				Payable[y]	Total	
Untreated	912 a	63 a	1,304 a	41.2 a	100 a	6.0 a	18.2 d	38.6 d	1,305
Dichloropropene (172 L)	1,087 a	1 e	213 bc	18.2 bcde	84 a	4.2 b	36.6 b	57.0 a	2,159
Dichloropropene (232 L)	1,430 a	1 e	28 de	20.7 bcd	86 a	4.4 b	37.0 ab	54.5 ab	2,052
Dichloropropene (172 L) + ethoprop 6E (6.5 kg) (PP)	1,198 a	1 e	30 e	1.3 e	3 c	0.1 d	44.4 a	54.7 ab	2,555
Dichloropropene (232 L) + ethoprop 6E (6.5 kg) (PP)	1,663 a	4 cde	6 f	0.6 e	0 c	0.0 d	48.4 a	52.3 ab	2,687
Dichloropropene (172 L) + aldicarb 15G (3.2 kg) (BD)	1,247 a	4 cde	100 cd	6.2 de	37 b	1.6 c	40.1 ab	55.0 ab	2,287
Dichloropropene (232 L) + aldicarb 15G (3.2 kg) (BD)	893 a	7 bcde	91 de	6.3 de	19 bc	0.9 cd	41.3 ab	53.8 ab	2,136
Ethoprop 6E (9.7 kg) (PP)	1,397 a	25 abcd	644 a	9.0 cde	28 b	1.4 c	35.9 b	48.7 bc	2,337
Ethoprop 6E (6.5 kg) (PP) + ethoprop 10G (3.2 kg) (PP)	1,190 a	24 abcd	939 a	9.3 cde	32 b	1.6 c	34.8 b	49.3 bc	2,252
Ethoprop 6E (6.5 kg) (BD) + aldicarb 15G (3.2 kg) (BD)	842 a	19 abc	788 a	6.2 de	19 bc	1.0 cd	38.8 ab	49.6 bc	2,459
Aldicarb 15G (3.2 kg) (BD)	1,412 a	60 ab	1,015 a	35.0 ab	92 a	5.1 ab	25.6 c	46.2 c	1,712
Aldicarb 15G (3.2 kg) (SD)	810 a	29 abc	710 ab	26.3 abc	99 a	5.5 a	23.8 cd	40.4 d	1,582

[t] Values are means of five replicates. Values in each column not followed by the same letter(s) differ significantly at $P = 0.05$ according to Duncan's multiple range test. Nematode data were transformed to $Log_n (X + 1)$ before analysis, but actual means are used in table.
[u] PP = preplanting, BD = postplant broadcast, and SD = postplant sidedress.
[v] Percent infection rated by a commercial processor (Chef Ready, Othello, WA) was based on payable tubers. Tubers with greater than 20% of peeled surface showing nematode signs were rejected and contributed to percent infection.
[w] Tubers with six or more nematodes were graded as culls (IAREC grading system).
[x] Infection index: 0 = no nematodes; 1 = 1–3, 2 = 4–5, 3 = 6–9, 4 = 10+, 5 = 50+, and 6 = 100+ nematodes per tuber (IAREC grading system).
[y] Payable yield = tubers greater than 113 g or 5 cm in diameter minus nematode and other culls.
[z] Estimated net return = (payable yield × $71.70/t) − (cost of control); dichloropropene at 172 L and 232 L cost $465 and $601/ha, respectively; ethoprop 3.2, 6.5, and 9.7 kg cost $36, $66, and $96, respectively; aldicarb at 3.2 kg cost $124/ha. All figures include application costs.

Table 2. Nematode population densities, potato yields, tuber infection, and estimated net return from *Meloidogyne chitwoodi* plots in 1984 metam-sodium fumigant trials[t]

Treatment and rate[u] (L a.i./ha)	*M. chitwoodi* juveniles/ 250 cm^3 of soil				Percent infection[v]	Percent cull[w]	Infection index[x]	Yield (t/ha)		Estimated net return[z] ($)
	Nov. 1983	Mar.	Jul.	Oct.				Payable[y]	Total	
Untreated	2,427 a	966 a	39 a	1,118 a	52.6 a	100 a	5.6 a	16.2 c	35.4 b	1,162
Metam-sodium (153) (F)	2,418 a	1 c	3 b	144 abc	0.5 b	22 b	1.2 b	37.0 ab	56.1 a	2,107
(184) (F)	2,192 a	1 c	5 b	8 bc	1.1 b	10 b	0.7 b	42.4 a	58.3 a	2,385
(153) (S)	···	806 a	2 b	179 abc	3.4 b	15 b	0.7 b	37.9 ab	56.3 a	2,171
(184) (S)	···	1,156 a	2 b	281 ab	3.4 b	18 b	0.9 b	36.8 ab	51.1 ab	1,984

[t] Values are means of three replicates with two samples per replicate.
[u] F = fall and S = spring.
[v] Percent infection rated by a commercial processor (Chef Ready, Othello, WA) was based on payable tubers. Tubers with greater than 20% of peeled surface showing nematode signs were rejected and contributed to percent infection.
[w] Tubers with six or more nematodes were graded as culls (IAREC grading system).
[x] Infection index: 0 = no nematodes; 1 = 1–3, 2 = 4–5, 3 = 6–9, 4 = 10+, 5 = 50+, and 6 = 100+ nematodes per tuber (IAREC grading system).
[y] Payable yield = tubers greater than 113 g or 5 cm in diameter minus nematode and other culls.
[z] Estimated net return = (payable yield × $71.70/t) − (cost of control); metam-sodium cost $1.20/L applied.

Dichloropropene greatly reduced J2 density in the soil but did not prevent high levels of tuber infection at harvest. This indicated that nematodes escaped a lethal fumigant dosage. Fumigant dosage in the soil is reduced by one-half for a one-half distance above 15 cm, such that dosage at a 2 cm depth is one-quarter that at 15 cm (5). In our study, low numbers of nematodes escaped a lethal fumigant dosage in the surface soil profile. A second source of reinfestation could be nematodes migrating up from below the fumigated soil profile. Active *M. chitwoodi* juveniles have been recovered from soil samples collected at 1.2–1.8 m (10). Metam-sodium (4) and dichloropropene (6) fumigants may not effectively control nematodes to this depth when applied by standard commercial methods. Greenhouse studies (*unpublished*) demonstrated that *M. chitwoodi* juveniles can migrate vertically 50 cm within 9 days, a distance that may separate unfumigated subsoil and plant roots. Santo and Qualls (12) reported that active *M. chitwoodi* juveniles could not be detected from the upper 92-cm soil profile after treatment with Vapam, a metam-sodium fumigant; at harvest, however, a low level of tuber infection was detected. In our study, a few nematodes migrating up into the root zone could infect roots and populations could increase by tuberization and invade tubers by harvest. The lower tuber infection with metam-sodium compared with dichloropropene could be accounted for by metam-sodium's more effective treatment of the surface profile, because it was applied as a drench.

Control of other nematode species in potato with fumigation has been enhanced with nonfumigant nematicides (14,16). Our data suggest that ethoprop protected plants from infection by nematodes remaining after fumigation. This would halt or retard the first generation development and suppress or delay second-generation J2 increase after tubers set. Ethoprop alone and ethoprop-aldicarb combinations reduced tuber infection but not to an acceptable level. This suggests that residual ethoprop concentrations in the hills may have been great enough to deter tuber invasion, although nematode populations increased in the distal root system. Trials are currently under way to evaluate early July nonfumigant treatment before tuber invasion and to determine if protection can be extended until harvest.

Ethoprop has low water solubility and was reported to have restricted downward movement below the area of incorporation (13). However, Brodie (1) reported that it effectively reduced root galling of tomato roots to 20 cm when incorporated to 5 cm. In our studies, ethoprop was incorporated to 10–15 cm. Upon hilling, treated soil was deposited above the seed piece. Minimal leaching and defusion of ethoprop would be adequate to treat the root zone. Ethoprop has been reported to have a half-life of 14–28 days in sandy loam (13) and to protect roots from nematode invasion for 8 wk after treatment (2). Aldicarb is more water-soluble than ethoprop and highly mobile in the soil (15). In sandy soils under sprinkler irrigation, aldicarb could be leached out of the root zone. This could account for the better control obtained with ethoprop in our study.

The goal of any nematode management program should be maximize and sustain economic return to the producer. Therefore, the commercially acceptable infection level must be considered when ranking dollar returns. In Washington, potato processors establish their own standards, which may vary according to availability of potatoes each year. Santo et al (11) stated that the rejection level in Washington ranged from 3 to 20% nematode culls between 1981–1984. Utilizing this standard, only dichloropropene-ethoprop treatments produced infection levels acceptable under the most severe criteria. Santo et al (11) reported that dichloropropene or a dichloropropane-dichloropropene mixture (DD) combination with ethoprop consistently provided excellent control under moderate nematode pressure. Conversely, the efficacy of dichloropropene, DD, and nonfumigant nematicides alone varied in that 5-yr small-plot study. In this commercial field study under severe nematode pressure, dichloropropene plus ethoprop also gave the least tuber infection and the largest net return. Commercial applicators also have had excellent *M. chitwoodi* control with metam-sodium-ethoprop combinations. The additional costs of multiple nematicide treatments may be warranted in areas with histories of severe nematode damage and high *M. chitwoodi* populations as insurance against crop rejection in years when nematode infection acceptance level is low.

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