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Control of *Paratrichodorus allius* and Corky Ringspot Disease of Potato in the Columbia Basin of Oregon[1]

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Abstract: Corky ringspot disease (CRS) of potato, caused by tobacco rattle virus that is vectored by stubby-root nematodes (*Paratrichodorus* spp.), is often controlled by aldicarb. When use of aldicarb on potato was suspended in 1989, an increase in crops rejected due to CRS in the Columbia Basin of the U.S. Pacific Northwest occurred. During 1992–94, several fumigant and nonfumigant nematicides were tested alone and in combination for control of *P. allius* and CRS. Aldicarb alone significantly reduced CRS but not to acceptable levels. Metam sodium or ethoprop alone did not control CRS, but metam sodium plus ethoprop provided adequate control under light disease pressure. Two or three post-emergence applications of oxamyl, either with or without metham sodium, appeared to control CRS at low pressure. Fosthiazate reduced CRS incidence when used alone but not in combination with metam sodium. At low *P. allius* population densities, 1,3 dichloropropene (1,3-D) controlled CRS at 94 liters/ha, and rates of 140 liters/ha or greater were adequate at higher population densities. Treatment with 1,3-D plus chloropicrin was no better than 1,3-D alone and did not always control CRS. Combinations of 1,3-D at 94 liters/ha or greater plus metam sodium at 374 liters/ha or greater controlled CRS. *Paratrichodorus allius* numbers were higher and severity of CRS greater after wheat than after field corn, but *P. allius* declined rapidly after potato was planted and remained at low levels until harvest.

Key words: 1,3-dichloropropene, aldicarb, chloropicrin, corky ringspot, ethoprop, fosthiazate, fumigants, metam sodium, nematicides, oxamyl, *Paratrichodorus,* potato, stubby-root nematode, tobacco rattle virus.

Potato growers in the Pacific Northwest region of the United States must manage populations of the northern root-knot nematode (*Meloidogyne hapla,* Chitwood) (Ingham et al., 1991), Columbia root-knot nematode (*Meloidogyne chitwoodi* Golden et al.) (Pinkerton et al., 1986), and stubby-root nematode (*Paratrichodorus allius* (Jensen) (Siddiqi), which are common in many potato fields in this growing area. *Paratrichodorus allius* alone is not a problem on potatoes but is a vector for tobacco rattle virus (Jensen and Allen 1964; Jensen et al., 1974), which causes corky ringspot disease (CRS), a very serious problem in potato. Corky ringspot disease, known as spraing in Europe, has been reported since the turn of the century and was likely what Paine (1918) described as Internal Rust Spot. While CRS was described in detail by Atanasoff in 1926, the existence of a nematode vector was not demonstrated until 1960 (Sol et al., 1960; Sol and Seinhorst, 1961). Corky ringspot disease was reported from the United States in 1946 (Eddins et al., 1946) and in the Pacific Northwest from Oregon in 1963 (Allen, 1963) and Washington in 1975 (Thomas, 1976). This disease produces dark-brown ‘‘corky’’ necrotic areas in the form of arcs or diffuse brown spots within the tuber (Atanasoff, 1926). Damaged tubers are not acceptable to processors and must be culled. Crops in which more than 6% of the tubers are graded as culls due to CRS damage are often rejected or downgraded in value.

Until 1990, the primary nematodes of concern to potato growers in the Columbia Basin of the U.S. Pacific Northwest were *M. chitwoodi* and *M. hapla.* Growers treated infested soils with metam sodium (sodium-N-methyldithiocarbamate), ethoprop, or both materials. Aldicarb was often applied during

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the last cultivation to control Colorado potato beetle (*Leptinotarsa decemlineata*) but also may have provided additional nematode suppression. Aldicarb has been documented to provide good control of stubby-root nematodes and CRS (Weingartner and Shumaker, 1990a) and, as a likely consequence of the widespread use of aldicarb, incidence of CRS in the Columbia Basin was rare (Thomas et al., 1993). When the use of aldicarb on potato was suspended in 1989 (Thomas et al., 1993), there was an immediate increase in frequency and severity of CRS in the Columbia Basin. Crops were rejected from several fields that had no history of this disease, including some that had been treated with metam sodium. The fumigant nematicide 1,3-dichloropropene (1,3-D) can be effective against *M. chitwoodi* (Griffin, 1989). However, 1,3-D was not used extensively on potato in the Columbia Basin of Oregon because growers depended on metam sodium to control *Verticillium dahliae* and potato early dying (Kunkel and Weller, 1965) as well as nematodes. The increase in CRS renewed grower interest in combinations of metam sodium and other nematicides in areas where both soilborne fungal diseases and nematodes occur. This paper reports the results of 3 years of research to evaluate alternatives to metam sodium and aldicarb for the control of *P. allius* and CRS.

MATERIALS AND METHODS

Plot design: Trials were conducted in commercial potato fields near Umatilla, Oregon, where potato crops had been rejected in 1990 because of excessive CRS. Study areas in 1992 and 1993 were in the same field, approximately 100 m apart, and 1994 plots were in a nearby field on the same farm. The 1992 study followed a wheat crop, and the 1993 and 1994 studies followed field corn. Soil type in the 1992 and 1993 sites was a Quincy loamy fine sand with 0 to 5% slope; in 1994 the soil type was a Quincy loamy fine sand with a gravelly substratum and 0 to 5% slope. In all three trials, 16.7-m × 4.9-m (approximately 5 rows wide) plots were established in a randomized-block design with 4 (1992) or 5 (1993 and 1994) replications. Seed spacing was 22.5 cm, and row spacing was 85 cm. All cultural practices were conducted by the cooperating grower and were consistent with typical procedures for that growing area. Potatoes (*Solanum tuberosum* cv. Russet Burbank) were harvested from the middle row of each plot with a single-row level bed digger. All tubers from the center 7.6 of that row were-collected and sorted by weight, and a random sample of 25 tubers (114–341 g) was collected for CRS evaluations.

Application methods: The descriptions of the nematicide treatments and abbreviations used in data tables are listed in Table 1. Broadcast applications of the soil fumigants 1,3-D and 1,3-D plus chloropicrin were injected 45 cm deep using shanks set 38 cm apart. Soil was sealed immediately with a disc and packer that followed behind the fumigator. Metam sodium (32% a.i. formulation) at the desired rates was delivered to the entire plot in 1.9 cm water through a portable sprinkler applicator, except for the 514-liters/ha treatment in 1994. In this case, plots that were not to receive this treatment were covered with plastic tarps and metam sodium was applied to the remaining plots through center pivot chemigation. Tarps were then removed and other rates applied through the portable sprinkler applicator. Ethoprop 10 G was broadcast by measuring the appropriate amount of material for each plot into an ACME gravity-flow Spread-Rite granule spreader (pbi/Gordon Corp., Kansas City, KS) and shaking out the material during at least two passes over the area to be treated. Fosthiazate was applied with a CO_2 backpack sprayer in a 365-liters/ha spray solution. Both ethoprop and fosthiazate were incorporated to 15 cm with a tractor-pulled rototiller immediately after application. Aldicarb 15 G was applied just before the last cultivation as a 10-cm band on each side of the hill via a Gandy (Gandy, Memphis, TN) box applicator with Lilliston (Albany, GA) extenders and incorporated into the soil with a dammer-diker. Foliar applications of oxamyl were made with a CO_2 backpack sprayer in a 150 to 187-liters/ha spray solu-

TABLE 1. Descriptions of treatments and abbreviations used in text and tables.

Abbreviation	Treatment description
Control	Untreated control
1,3-D 94	1,3-dichloropropene[a] at 94 liters/ha
1,3-D 140	1,3-dichloropropene at 140 liters/ha
1,3-D 187	1,3-dichloropropene at 187 liters/ha
1,3-D 234	1,3-dichloropropene at 234 liters/ha
1,3-D + chloropicrin	1,3-dichloropropene with 17% chloropicrin[b] at 257 liters/ha
MS 514	Metam sodium[c] at 514 liters/ha
MS 701	Metam sodium at 701 liters/ha
MS 935	Metam sodium at 935 liters/ha
Ethoprop 13	Ethoprop 10 G[d] at 13.2 kg a.i./ha
Aldicarb 3	Aldicarb 15 G[e] at 3.3 kg a.i./ha
Oxamyl 3X	Three foliar applications of oxamyl[f] at 1.1 kg a.i./ha
Fosthiazate 6	Fosthiazate[g] at 6.6 kg a.i./ha
1,3-D 94 + MS 514	1,3-dichloropropene at 94 liters/ha + metam sodium at 514 liters/ha
1,3-D 140 + MS 514	1,3-dichloropropene at 140 liters/ha + metam sodium at 514 liters/ha
1,3-D 187 + MS 514	1,3-dichloropropene at 187 liters/ha + metam sodium at 514 liters/ha
1,3-D 94 + MS 374	1,3-dichloropropene at 94 liters/ha + metam sodium at 374 liters/ha
1,3-D 140 + MS 374	1,3-dichloropropene at 140 liters/ha + metam sodium at 374 liters/ha
1,3-D 140 + ethoprop 13	1,3-dichloropropene at 140 liters/ha + ethoprop 10 G at 13.2 kg a.i./ha
MS 514 + oxamyl 1X	Metam sodium at 514 liters/ha + one foliar application of oxamyl at 1.1 kg a.i./ha
MS 514 + oxamyl 2X	Metam sodium at 514 liters/ha + two foliar applications of oxamyl at 1.1 kg a.i./ha
MS 514 + oxamyl 3X	Metam sodium at 514 liters/ha + three foliar applications of oxamyl at 1.1 kg a.i./ha
MS 514 + ethoprop 13	Metam sodium at 514 liters/ha + ethoprop 10 G at 13.3 kg a.i./ha
MS 514 + fosthiazate 6	Metam sodium at 514 liters/ha + fosthiazate at 6.6 kg a.i./ha

[a] Telone II, Dow Elanco, Indianapolis, IN.
[b] Telone C-17, Dow Elanco, Indianapolis, IN.
[c] Vapam, 32% a.i. formulation, AMVAC Chemical Corp., Los Angeles, CA.
[d] Mocap 10G, Aventis CropScience, Research Triangle Park, NC.
[e] Temik 15G, Aventis CropScience, Research Triangle Park, NC.
[f] Vydate L, DuPont Agricultural Products, Wilmington, DE.
[g] Fosthiazate 900 EC, ISK Biosciences, Mentor, OH.

tion and followed by overhead irrigation within 24 hours.

Nematode sampling: Soil samples for nematode assay (ten 2.5-cm-diam. cores/plot) at depths of 0 to 30 cm and 30 to 60 cm were taken from the center row of each plot. No samples were taken within 1.5 m of either end of the plot. Soil samples were sieved and mixed, and nematodes were extracted from 250-g subsamples by density centrifugation (Jenkins, 1964) as modified in Ingham (1994).

CRS evaluations: Tubers were cut longitudinally to inspect for symptoms of CRS according to U.S. Department of Agriculture standards (USDA, 1991). If no or only slight symptoms were found, the tubers were further sliced into 1.3-cm-thick transverse sections. Only spots or arcs exceeding 0.3 cm in diameter were counted. Tubers were placed into categories of ''any damage'' = total incidence of tubers with any symptoms of CRS regardless of severity, ''acceptable damage'' = 0 to 5% waste ($\leq$1 spot or arc per 57 g of tuber), ''serious damage'' = 5 to 10% waste (1 to 2 spots or arcs per 57 g of tuber), and ''culls'' = greater than 10% waste. Tubers with up to 5% waste are considered as No. 1s, tubers with 5 to 10% waste are considered No. 2s, and culls are rejected by industry standards.

Statistical analysis: All percent damage data were transformed to arcsin square root (x) and evaluated by analysis of variance (ANOVA). Nematode densities were adjusted for soil moisture to convert to densities/250 g dry soil and transformed to $\log_{10}(x + 1)$ before analysis (ANOVA). Least significant difference (LSD) was used to separate means only when the ANOVA was significant at $P \leq 0.05$.

1992 study: 1,3-dichloropropene and 1,3-D plus chloropicrin were applied on 25 October 1991 and metam sodium on 4 November 1991. Soil temperature at 20 cm was 13 °C on both dates. Ethoprop was applied and incorporated on 18 March 1992. Russet Burbank potato was planted 14 April 1992. Aldicarb was applied on 22 May, and oxamyl was applied on 18 June and 16 July. Nematode samples were collected before fumigation (23 October 1991), before planting and ethoprop or aldicarb application (17 March 1992), midseason (18 August), and at harvest (1 October).

1993 study: 1,3-dichloropropene and 1,3-D plus chloropicrin were applied on 26 March 1993 and metam sodium on 3 to 5 April when soil temperature was 12 °C at 10 cm and 7 °C at 45 cm. Ethoprop and fosthiazate were applied and incorporated on 15 April when soil temperature at 20 cm was 11 °C. The study area was planted to potato cv. Russet Burbank on 22 April. Foliar applications of oxamyl were made on 31 May, 10 June, and 20 June. All plots were sampled for nematodes when plots were established (25 November 1992), before fumigation (15 March), after fumigation (14 April), early midseason (7 July), late midseason (24 August), and at harvest (14 October; 0 to 30 cm only).

1994 study: 1,3-dichloropropene was applied on 10 March 1994 when soil temperature was 9 °C at a depth of 15 cm and 5 °C at a depth of 45 cm. Center pivot application of metam sodium occurred on 25 March, and sprinkler applications were made on 1 and 2 April when soil temperature was 12 °C at a depth of 15 cm. The study area was planted to potato cv. Russet Burbank on 14 April. Foliar applications of oxamyl were made on 3 June, 3 July, and 2 August. Potatoes were harvested on 29 September. All plots were sampled for nematodes before fumigation (7 March), after fumigation (26 April), at midseason (11 August), and at harvest (29 September).

RESULTS

1992 nematode densities: Prefumigation densities of *P. allius* over the entire study area averaged 44 and 20/250 g dry soil in the 0 to 30-cm (Table 2) and 30 to 60-cm (Table 3) layers, respectively. Population densities in all untreated plots (the controls and plots to receive aldicarb) averaged 29/250 g soil in the fall (1991) and 30/250 g soil in the spring (1992) at the 0 to 30-cm depth, and 20/250 g soil in the fall and 18/250 g soil in the spring at 30 to 60 cm, indicating no change in recoverable densities over the winter at either depth. In spring post-fumigation samples, *P. allius* was present only in the top 30 cm in untreated plots (controls and plots to receive aldicarb), plots treated with 1,3-D at 140 or 187 liters/ha, and in the three treatments that received

TABLE 2. Effects of nematicides on population densities (nematodes/250 g dry soil) of stubby-root nematodes (*Paratrichodorus allius*) from 0 to 30 cm deep in a potato field at Umatilla, Oregon, 1992.

	1991	1992		
Treatments[a]	23 October[b]	17 March[c]	18 August	1 October[d]
Control	13 ab[e]	26 d	<1	2 b
Aldicarb 3	45 bcd	34 d	2	0 a
1,3-D 140	40 cd	1 ab	0	0 a
1,3-D 187	26 abc	<1 a	0	0 a
1,3-D 234	51 cd	0 a	0	<1 ab
1,3-D + chloropicrin	51 cd	0 a	<1	0 a
MS 514	81 d	2 ab	2	<1 ab
MS 701	44 cd	5 bc	0	<1 ab
MS 935	34 bcd	2 ab	1	<1 ab
1,3-D 187 + MS 514	50 cd	0 a	0	0 a

[a] See text for full description of treatments.
[b] Before fumigation.
[c] After fumigation.
[d] At harvest.
[e] Means within the same column that are followed by the same letter are not significantly different ($P \leq 0.05$).

TABLE 3. Effects of nematicides on population densities (nematodes/250 g dry soil) of stubby-root nematodes (*Paratrichodorus allius*) from 30 to 60 cm deep in a potato field at Umatilla, Oregon 1992.

	1991		1992	
Treatments[a]	23 October[b]	17 March[c]	18 August	1 October[d]
Control	8	9 b[e]	2 b	6 b
Aldicarb 3	32	26 c	0 a	0 a
1,3-D 140	16	0 a	1 b	0 a
1,3-D 187	18	0 a	0 a	0 a
1,3-D 234	25	0 a	0 a	<1 a
1,3-D + chloropicrin	17	0 a	0 a	0 a
MS 514	29	<1 a	0 a	4 ab
MS 701	25	0 a	0 a	0 a
MS 935	12	<1 a	0 a	1 ab
1,3-D 187 + MS 514	20	0 a	0 a	0 a

[a] See text for full description of treatments.

[b] Before fumigation.

[c] After fumigation.

[d] At harvest.

[e] Means within the same column that are followed by the same letter are not significantly different ($P \leq 0.05$).

metam sodium alone. Numbers in the second 30 cm were detectable in untreated plots and in two of the three metam sodium treatments. By mid-August, densities in untreated plots had declined to an average of <1 and 2/250 g soil in the first and second 30 cm, respectively. Stubby-root nematodes were detected in the top 30 cm in plots treated with aldicarb, 1,3-D plus chloropicrin, or metam sodium and were found in the second 30 cm in plots with the lowest rate of 1,3-D. Densities at harvest in untreated plots averaged 2/250 g soil in the first 30 cm and 6/250 g soil in the second 30 cm. The only other *P. allius* detected at either depth was from plots treated with 1,3-D at 234 liters/ha or with any rate of metam sodium alone.

1992 CRS tuber damage: Disease pressure at this site was high, and all treatments had an equally high incidence of tubers with any CRS symptoms (Table 4). In regard to CRS severity, tubers were either undamaged to slightly damaged (acceptable damage) or severely damaged (culls) by CRS. Few tubers were found with ''serious damage,'' and there was no treatment effect on the number of seriously damaged tubers. Treatment performance could be divided into three

TABLE 4. Effects of nematicides on internal damage (% of potato tubers examined) from corky ringspot at Umatilla, Oregon, 1992.

Treatment[a]	Any damage[b]	Acceptable damage[c]	Serious damage[d]	Culls[e]
Control	93	10 a[f]	8	81 c
Aldicarb 3	82	78 b	5	17 b
1,3-D 140	57	77 bc	18	5 ab
1,3-D 187	53	98 cd	1	1 a
1,3-D 234	100	97 cd	0	3 ab
1,3-D + chloropicrin	60	86 bcd	2	12 ab
MS 514	98	26 a	9	65 c
MS 701	86	31 a	9	60 c
MS 935	90	23 a	3	73 c
1,3-D 187 + MS 514	51	90 bcd	5	5 ab

[a] See text for full description of treatments.

[b] Tubers with any symptoms of corky ringspot.

[c] 0 to 5% waste = one 0.3-cm-diam. spot or arc/57 g of tuber. These tubers may still be considered No. 1s.

[d] 5–10% waste = two 0.3-cm-diam. spots or arcs/57 g of tuber. These tubers would be considered No. 2s.

[e] More than 10% waste = more than two 0.3-cm-diam. spots or arcs/57 g of tuber. These tubers would be rejected.

[f] Means within the same column that are followed by the same letter are not significantly different ($P \leq 0.05$).

classes. Incidence of CRS culls in plots treated with any rate of metam sodium alone did not differ from that in untreated plots. Aldicarb and 1,3-D plus chloropicrin reduced damage, but the percentage of culls was still unacceptable. All other treatments resulted in little damage from CRS and met industry standards for quality. Combinations of 1,3-D at 234 liters/ha plus aldicarb, ethoprop, or oxamyl lowered the percentage of culls to near zero (data not shown).

1993 nematode densities: Populations of *P. allius* across all plots in fall 1992 averaged 2 and 5/250 g soil in the 0 to 30-cm and 30 to 60-cm depths, respectively, and before spring fumigation averaged 2 and 4/250 g soil in the 0 to 30-cm and 30 to 60-cm depths, respectively. Even though these densities were much lower than those in the 1992 study, they suggest little decline in population density over the winter. At fumigation, *P. allius* averaged 2/250 g dry soil at both depths in plots that had not been fumigated and 0/250 g dry soil at both depths in fumigated plots. By early July, *P. allius* had declined in all plots and remained low for the rest of the study. Population data from individual treatments are not presented for this study.

1993 CRS tuber damage: Similar to *P. allius* densities, total incidence of CRS and the percentage of culled tubers were much lower in 1993 than in 1992 and were not affected by metam sodium alone or metam sodium plus fosthiazate (Table 5). Treatments with fosthiazate or ethoprop alone had fewer culls than the control, but these levels were likely still too high to be acceptable to processors. All other treatments resulted in acceptable tubers under the disease pressure present in this study.

1994 stubby-root nematode densities: Across all plots, population densities of *P. allius* before fumigation averaged 2/250 g soil in both the first and second 30 cm (data not presented). After fumigation, stubby-root nematodes were not detected in any treatment except in the 30 to 60-cm sample from non-1,3-D treatments at harvest, where low densities were recovered.

1994 CRS tuber infection: Metam sodium at 514 liters/ha did not reduce total incidence of tubers with any CRS but did lower the percentage of tubers culled because of CRS (Table 6). However, the level of culls (28%) would not have been acceptable to processors. All treatments with metam sodium plus 2 or 3 oxamyl applications reduced the per-

TABLE 5. Effects of nematicides on internal damage (% of potato tubers examined) from corky ringspot at Umatilla, Oregon, 1993.

Treatment[a]	Any damage[b]	Acceptable damage[c]	Serious damage[d]	Culls[e]
Control	48 fg[f]	69 ab	12 f	19 c
Ethoprop 13	28 de	84 bcde	8 ef	8 ab
Oxamyl 3X	14 bcd	93 defg	6 def	1 a
Fosthiazate 6	20 cde	89 efg	5 cde	6 ab
MS 514	49 fg	71 abc	10 e	19 c
1,3-D 140	6 ab	98 fg	2 abcd	0 a
1,3-D 187	7 abc	99 fg	0 a	1 a
1,3-D 234	2 a	99 g	1 bc	0 a
1,3-D + chloropicrin	3 a	98 fg	1 ab	1 a
MS 514 + ethoprop 13	26 de	86 cde	9 ef	5 ab
MS 514 + oxamyl 3X	20 cde	91 def	6 cdef	4 ab
MS 514 + fosthiazate 6	37 efg	79 bcde	6 cdef	15 bc
1,3-D 187 + MS 514	12 abcd	98 fg	0 a	2 a
1,3-D 140 + ethoprop 13	10 abc	98 fg	2 abc	0 a

[a] See text for full description of treatments.

[b] Tubers with any symptoms of corky ringspot.

[c] 0 to 5% waste = one 0.3-cm-diam. spot or arc/57 g of tuber. These tubers may still be considered No. 1s.

[d] 5–10% waste = two 0.3-cm-diam. spots or arcs/57 g of tuber. These tubers would be considered No. 2s.

[e] More than 10% waste = more than two 0.3-cm-diam. spots or arcs/57 g of tuber. These tubers would be rejected.

[f] Means within the same column that are followed by the same letter are not significantly different ($P \leq 0.05$).

TABLE 6. Effects of nematicides on internal damage (% of potato tubers examined) from corky ringspot at Umatilla, Oregon, 1994.

Treatment[a]	Any damage[b]	Acceptable damage[c]	Serious damage[d]	Culls[e]
Control	77 e[f]	38 a	18 b	44 d
MS 514	65 e	52 a	20 b	28 c
MS 514 + oxamyl 1X	67 e	53 a	26 b	21 c
MS 514 + oxamyl 2X	19 cd	94 bc	2 a	3 ab
MS 514 + oxamyl 3X	35 d	86 b	4 a	11 b
1,3-D 94	7 abc	100 c	0 a	0 a
1,3-D 140	12 bc	98 c	1 a	1 a
1,3-D 187	2 a	100 c	0 a	0 a
1,3-D 234	12 bc	97 bc	2 a	1 a
1,3-D 94 + MS 514	8 abc	98 c	1 a	1 a
1,3-D 140 + MS 514	6 ab	100 c	0 a	0 a
1,3-D 187 + MS 514	11 abc	98 c	0 a	2 a
1,3-D 94 + MS 374	9 abc	96 bc	4 a	0 a
1,3-D 140 + MS 374	18 bc	96 bc	2 a	2 ab

[a] See text for full description of treatment.

[b] Tubers with any symptoms of corky ringspot.

[c] 0 to 5% waste = one 0.3 cm-diam. spot or arc/57 g of tuber. These tubers may still be considered No. 1s.

[d] 5–10% waste = two 0.3 cm-diam. spots or arcs/57 g of tuber. These tubers would be considered No. 2s.

[e] More than 10% waste = more than two 0.3 cm-diam spots or arcs/57 g of tuber. These tubers would be rejected.

[f] Means within the same column that are followed by the same letter are not significantly different ($P \leq 0.05$).

centage of culled tubers over that with metam sodium alone, but only the treatment with two applications of oxamyl met industry standards. All treatments that received 1,3-D at any rate had acceptable levels of CRS.

DISCUSSION

Potato was a poor host for *P. allius,* and population densities declined even in untreated plots during each season after potato was planted. Population densities were low prior to planting in both 1993 and 1994, and it was difficult to find any *P. allius* after potato was planted either year. Mojtahedi and Santo (1999) also observed *P. allius* to decline rapidly after planting potato and remain at a low density during the potato crop. Differences in initial populations between 1992 and 1993 or 1994 were probably due to previous crops of wheat (a good host for *P. allius*) in 1992 and field corn (a poor host) in both 1993 and 1994 (Mojtahedi and Santo, 1999). However, even low populations were capable of spreading TRV to potato plants, and as few as 2 *P. allius*/250 g dry soil at planting resulted in heavy CRS damage, particularly during 1992. Since *P. allius* densities declined little over the winters of 1991–92 and 1992–93, growers should be wary when planting potato after wheat in fields with a history of CRS.

Performance of nonfumigant nematicides: Aldicarb alone reduced cullage due to CRS damage, but the level of culls after treatment (17%) suggests that some infection may have occurred between planting (14 April) and aldicarb application (22 May). Grower experiences in the region suggest that aldicarb is generally sufficient to control CRS. Numerous trials in Florida (1977–1981) also indicate that aldicarb generally provides good control of CRS (Weingartner et al., 1983) but may not be sufficient under high disease pressure (Weingartner and Shumaker, 1990b). Aldicarb in combination with 1,3-D reduced the incidence of CRS to 5% and 0.4% in 1982 and 1983, respectively, compared to 46% and 15%, respectively, in treatments with 1,3-D alone (Weingartner and Shumaker, 1990a). Consequently, aldicarb has been used either alone or in combination with a soil fumigant on up to 95% of the potato hectarage in Florida. The high incidence of CRS after aldicarb application in the current study may have been due to high disease pressure (81% culls in untreated plots), late application, or the fact that aldicarb was not used in combination with metam sodium, as is commonly practiced in the Columbia Basin. Unfortunately, when the use of aldicarb on potatoes was suspended, there was little incentive to test it in the 1993 and 1994 studies.

Suppression of CRS damage by oxamyl in this study is consistent with Weingartner et al. (1983), who also found 2 to 3 foliar applications of oxamyl to control CRS, and Alphey et al. (1975), who reduced CRS with preplant broadcast applications of oxamyl granules. Similarly, substantial *P. allius* damage to onions was averted with a low dose rate of oxamyl (Ingham et al., 1999).

Although ethoprop eliminated CRS symptoms when combined with metam sodium and was nearly acceptable (8% culls) when used alone under the low disease pressure in our tests, it is doubtful that these treatments would be sufficient in a field with higher disease pressure. Ethoprop provided acceptable control of CRS in Scotland (Brown and Sykes, 1973), but it reduced CRS only from 28% to 20% in Florida (Weingartner and Shumaker, 1983). However, the rate used in Florida was only 25% of that used in the current study.

Effects of fosthiazate on CRS were difficult to interpret, and more testing is required. While fosthiazate alone resulted in fewer culls than in untreated plots, the metam sodium plus fosthiazate treatment did not lower the percent culls more than with metam sodium alone.

Other nonfumigants also have been inconsistent in control of CRS. Carbofuran, a carbamate nematicide like oxamyl, reduced CRS in one study, but damage was unchanged in another trial (Weingartner and Shumaker, 1983). Similarly, Alphey et al. (1975) observed a reduction in CRS with fenamiphos in 1972 but not in 1973. Therefore, results from the current study and previous research suggest that more work on rates and application times is necessary before nonfumigant nematicides alone may provide reliable control of CRS.

Performance of fumigant nematicides: Although metam sodium reduced *P. allius* population densities, it did not control CRS, even at high (935 liters/ha) rates. Weingartner and Shumaker (1988) reported that inrow injection of metam sodium also failed to control CRS.

In contrast, 1,3-D was very effective at reducing population densities of *P. allius* and the percentage of CRS culls to near zero. Dallimore (1972) also found 1,3-D effective for controlling CRS in Idaho, although the rates used (234–327 liters/ha) were much higher than in the current study. However, 1,3-D failed to control CRS in Florida (Weingartner et al., 1983; Weingartner and Shumaker, 1990b). The fumigation failure in Florida has been attributed, in part, to the ability of *P. minor* to migrate upward from below the fumigation zone into treated soil once the fumigant has dissipated (Weingartner et al., 1983). However, Mojtahedi and Santo (1999) observed only slow and limited vertical migration by *P. allius* in studies in the Pacific Northwest, and there was little evidence of vertical migration of *P. allius* in our study over three seasons. In addition, the rate used in the Florida trials (56 liters/ha) was much lower than those used in the current studies (94–234 liters/ha) and fumigant placement in Florida (depths of 25 to 30 cm) was not as deep as in Oregon (45 cm).

There appeared to be no advantage to the 1,3-D plus chloropicrin formulation over 1,3-D alone for control of CRS in our studies, and a similar conclusion was reached by Dallimore (1972). Similarly, Weingartner and Shumaker (1990a) found marginal or no significant differences in control of CRS or *P. minor* with ethylene dibromide (EDB) plus chloropicrin compared to EDB alone. Livingston et al. (1976) found little CRS after fumigation with 1,3-D plus chloropicrin but were able to recover TRV from bait plants grown in the fumigated soil. They concluded that this treatment may have short-term benefits, but that inoculum remained for the disease to reoccur.

Implications: Rejection of potato crops due to damage from CRS was virtually unknown in the Columbia Basin until aldicarb application on potato was suspended in 1989. Potatoes in several fields were rejected in 1990 and many others in following years. It appears that both *P. allius* and TRV have been present in the area without grower knowledge, but that CRS had been suppressed with the combined use of metam sodium for control of soilborne fungal pathogens and aldicarb for insect control. The symptoms of rings and arcs of dark-brown corky tissue considered characteristic of CRS were rarely observed in this study. The predominant symptoms were diffuse brown spots of corky tissue typical of CRS in Russet Burbank (Anonymous, 1992). These symptoms are similar to those of the physiological disorder, internal brown spot (IBS), which is also common in this growing region. It is possible that low levels of CRS may have occurred prior to the suspension of aldicarb but were mistakenly identified as IBS.

Higher levels of *P. allius* and CRS in potatoes after wheat in 1992 were in contrast to low levels of nematodes and CRS following corn in 1993, using plots very close to those in 1992, and in the 1994 study. These results suggest that wheat may be a much better host for *P. allius* than corn, which may aggravate CRS problems when potato follows wheat in rotation.

This study demonstrates that chemigation of metam sodium alone is not effective against CRS. This may explain the outbreak of CRS after the aldicarb suspension when growers continued to use metam sodium but switched to insecticides that did not have nematicidal activity, 1,3-dichloropropene was effective at reducing CRS at all rates tested, and the deep, sandy soils in the area appear to provide an optimum environment for maximum effectiveness of this fumigant. However, 1,3-D provides no control of soilborne fungal pathogens that are commonly controlled by metam sodium (Ingham and Hamm, unpubl. data). Thus, for maximum yields and high quality, growers need to use metam sodium for maintaining yield and either 1,3-D or a nonfumigant nematicide to control CRS. Metam sodium plus ethoprop, or two or three foliar applications of oxamyl, were effective at the nematode population densities that were present but may be inadequate under greater nematode pressure, as seen in 1992. Thus, the optimum treatment for reliable quality and yield in fields where both nematodes and soilborne fungal pathogens are present may be a combination of metam sodium and 1,3-D. In fields without soilborne fungal pathogens, 1,3-D alone would be sufficient. There was no advantage of combinations of nonfumigants with 1,3-D, even at low rates of 1,3-D (140 liters/ha).

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