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Effects of In-furrow and Water-run Oxamyl on *Paratrichodorus allius* and Corky Ringspot Disease of Potato in the Klamath Basin

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Abstract: Corky ringspot disease (CRS) of potato (*Solanum tuberosum*) is caused by the tobacco rattle virus (TRV), which is vectored by stubby-root nematodes, *Paratrichodorus* spp. and *Trichodorus* spp., and is a significant threat to potato quality and production in many areas of the western United States. Between 2002 and 2005, fields with a history of CRS were planted to potato and treated with various combinations of in-furrow (IF) and chemigated (water run, WR) oxamyl [Methyl N'N'-dimethyl-N-[(methyl carbamoyl)oxy]-1-thiooxamimidate] applications. Soil samples were collected to determine how *Paratrichodorus allius* populations responded to the various treatment regimes (2002-2004); potato tubers were evaluated for symptoms of CRS in 2004-2005. Applications of oxamyl to potato (1.1 kg a.i./ha) did not cause significant mortality of *P. allius* but did prevent the populations from increasing. Oxamyl applications that began at 55 days after planting (DAP) or later did not control CRS and were not different from the untreated control. However, application schedules that began early-season, either IF at planting, early WR (33 – 41 DAP), or both, significantly reduced CRS expression in cv. Yukon Gold. Therefore, oxamyl applications must be made early in the growing season to be effective in controlling CRS. Effects of oxamyl on CRS may be due to nematostatic action that suppresses feeding activity during early field season when most virus transmission probably occurs.

Key words: corky ringspot, CRS, oxamyl, population dynamics, potato, *Solanum tuberosum*, stubby-root nematodes, *Paratrichodorus* spp., *Trichodorus* spp., tobacco rattle virus, TRV, Yukon Gold.

Corky ringspot disease (CRS) of potato (*Solanum tuberosum*), also referred to as spraing, is caused by tobacco rattle virus (TRV) which is vectored by stubby-root nematodes (SRN), *Paratrichodorus* spp., and *Trichodorus* spp. (Walkinshaw et al., 1961; Harrison and Robinson, 1986). CRS symptoms vary depending on virus strain (Mojtahedi et al., 2001), potato cultivar (Brown et al., 2000), and time of infection (Weingartner et al., 1975). Symptoms often consist of brown necrotic rings, arcs, and diffuse spots (Atanasoff, 1926; Mojtahedi et al., 2001). Such symptoms cause potato quality defects and can result in devaluation or rejection of both fresh and processed potatoes. CRS is a problem of concern in many potato production areas of the western United States where the vector *P. allius* (Jensen, 1963) Siddiqi, 1974 and TRV have been found (Jensen and Allen, 1964; Mojtahedi and Santo, 1999). CRS also occurs in Florida, where it is vectored by *P. minor* (Weingartner and Shumaker, 1990), and has been recently reported from Michigan (Kirk et al., 2008), Minnesota, Wisconsin (Gudmestad et al., 2008), and North Dakota (David et al., 2010) where the vector has not been identified.

CRS can be controlled by managing the nematode vector (Brown et al., 2007). Aldicarb, a systemic carbamate pesticide, provides good suppression of CRS (Weingartner and Shumaker, 1990; Rykbost et al., 1992) but not always to acceptable levels (Ingham et al., 2007). However, harvest interval restrictions have limited its use in most short-season production areas in the western United States. The fumigant 1,3-dichloropropene (1,3-D) was effective at reducing CRS at various rates tested in the Columbia Basin of Oregon (Ingham et al., 2000). However, it failed to control CRS in Florida (Weingartner and Shumaker, 1990) and the Klamath Basin of southern Oregon (Rykbost et al., 1995). Fumigation failure in Florida may be attributed to the ability of *P. minor* to migrate from deeper, non-treated areas in the soil profile to upper treated areas once the active ingredient has dissipated; it is uncertain if *P. allius* migration is responsible for similar observations in the Klamath Basin. Metam sodium (sodium-N-methyldithiocarbamate) delivered through irrigation is not effective against CRS (Ingham et al., 2000), but is more effective when mechanically shanked in (Ingham et al., 2007). Several studies have evaluated the efficacy of ethoprop (O-Ethyl S, S-Dipropyl Phosphorodithioate) and carbofuran (2,3-Dihydro-2,2-dimethyl-7-benzofuranylmethylcarbamate), but results have been inconsistent (Brown and Sykes, 1973; Weingartner and Shumaker, 1983; Ingham et al., 2000).

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CRS can be also controlled by using TRV-resistant potato cultivars (Ingham et al., 2000), however, most available cultivars lack important characteristics required by both fresh and processing sectors in the western United States. Crop rotation using non-hosts such as alfalfa (*Medicago sativa* L.) or Scotch spearmint (*Mentha cardiaca* Baker) may provide control of CRS (Mojtahedi et al., 2002; Boydston et al., 2004). However, these crops must fit into current crop rotational schemes and must be kept free of weed hosts for TRV to be effective.

Suppression of CRS using oxamyl has been promising (Alphey et al., 1975; Alphey, 1978; Weingartner and Shumaker, 1983; Ingham et al., 1999; Ingham et al., 2000) but the optimal timing for applications is unknown. Further research is needed to optimize efficacy in suppressing viruliferous stubby-root nematodes and transmission of TRV to potato. The objective of this research was to determine the effects of multiple applications of oxamyl applied at different times on populations of the TRV vector, *P. allius* and CRS symptoms in potato tubers. Little information is available on changes in population densities of *P. allius* in potato or on the effects of oxamyl on *P. allius*. Application schedules began at planting, at crop emergence, or early mid-season (approximately 800 DD_{5C}) corresponding to the beginning of an oxamyl program for suppression of tuber damage from Columbia root-knot nematode (CRKN, *Meloidogyne chitwoodi*) (David et al., 2004).

Materials and Methods

Study Location: This field research was conducted at the Klamath Basin Research and Extension Center (KBREC) in Klamath Falls, Oregon. Studies evaluating the efficacy of oxamyl for control of CRKN were initiated at KBREC in 2002 and 2003 (David et al., 2004). Effects of oxamyl on *P. allius* and population dynamics data from these trials are included here to complement data collected during 2004 and 2005. Study areas in 2004 and 2005 were located approximately 305 m apart and were planted to spring cereals and orchardgrass (*Dactylis glomerata* L.) in each of the previous three years, respectively. The soil at both trial sites was classified as Fordney loamy fine sand with a pH of approximately 6.5 and an organic matter content of 1.5 percent in the plow layer. Potatoes were last grown in 2000 and 1999 for the 2004 and 2005 trial sites, respectively.

Site Determination: Soil samples for nematode assay (twenty-five 2.5-cm-diam. cores/area) at depths of 0 to 30 cm were taken the previous October in both trial years (2004 and 2005) to locate areas with sufficient populations of *P. allius*. Soil samples were sieved and mixed, and nematodes were extracted from 250-g subsamples by density centrifugation (Jenkins, 1964) as modified in Ingham (1994). Additional soil was sent to the USDA ARS Vegetable and Forage Crop Research Unit located in Prosser, WA to determine the presence or absence of TRV by growing Samsun NN tobacco (*Nicotiana tabacum*) in soil subsamples for visual CRS diagnosis on leaf tissues. All samples that harbored *P. allius* caused typical CRS lesions on Samsum NN tobacco (Mojtahedi, personal communication).

Experimental Design: Production practices for all trial years were consistent with commercial practices for the Klamath Basin. Trial areas were divided into four-row plots, 3.3 m by 6.1 or 7.6 m, and treatments were assigned in a randomized block design with five replications. In 2002 and 2003, all rows were planted to cv Russet Norkotah but in 2004 and 2005, one of the center rows was planted to cv. Yukon Gold as a better indicator cultivar for CRS while the other three rows were planted to cv. Russet Norkotah for CRKN damage and yield assessments (data not shown). All data were collected from the middle 4.6 m of the two center rows of each plot.

Application Procedures: All in-furrow (IF) applications of oxamyl were made at planting (0 days after planting, DAP) by leaving the furrow open after planting, applying oxamyl at a broadcast rate of 1.1 kg a.i./ha (equivalent to 5.9 kg a.i./ha in the treated area) or 2.2 kg a.i./ha in a 10-cm band over the seed-piece, and then closing the furrow. The application was made with a single-nozzle hand-held boom on a CO_2 backpack sprayer using an 8003 nozzle at 2.1 kg/cm. Spray volume of treated area was 692 l/ha and spray solutions were buffered to 5.0 pH. All chemigated applications were made at 1.1 kg a.i./ha injected into the irrigation system at 10.5 kg/cm using a piston pump calibrated to deliver approximately 26.5 l of spray solution per hour. Oxamyl was injected during the middle portion of the irrigation set (50 % of total irrigation duration) and was preceded and followed by irrigation water alone (25 % of total irrigation duration, respectively). This chemigation protocol was designed to move oxamyl into the root zone and minimize irrigation deficiencies to non-treated plots. To prevent application to plots not intended to receive oxamyl on particular dates, hoop frames constructed of PVC were placed in these plots and covered with plastic tarps during the injection period. Descriptions of treatments used are listed below and represent 1.1 kg a.i/ha of oxamyl, unless otherwise specified. Treatments consisted of an untreated control and oxamyl applications made at various intervals in DAP in 2002, 2003, 2004, and 2005 (See Table 1).

Effects of oxamyl on populations of P. allius: Soil samples (ten 2.5-cm-diam. cores/plot) from a depth of 0-30 cm were collected from the middle 3 m of the center two rows at planting and harvest (2002-2005) to evaluate how population densities responded to the various treatment regimes. Selected treatments were sampled from one row at one to two week intervals to monitor how population dynamics of *P. allius* responded to treatment applications during the growing season. Treatments and sample dates for the following years were:

TABLE 1. Population densities (nematodes/250 g dry soil) of stubby-root (*Paratrichodorus allius*) nematodes at planting and harvest of potato cv Russet Norkotah (2002 and 2003) and cv Yukon Gold (2004 and 2005) treated with oxamyl (1.1 kg a.i./ha), Klamath Falls, OR.

2002 Treatments[a]	21 May[b]	16 Sep[c]	2003 Treatments	22 May[b]	22 Sep[c]
1) Control	3	8	1) Control	6	6
2) 64, 79, 94	9	5	2) 56	6	8
3) 0, 64	4	2	3) 0, 56	9	12
4) 0, 64, 79	2	1	4) 0, 32, 56	6	6
5) 0, 64, 79, 94	2	2	5) 0 (2x), 56	5	3
	ns[d]	ns		ns	ns

2004 Treatments	26 May[b]	7 Oct[c]	2005 Treatments	26 May[b]	27 Sep[c]
1) Control	14	30	1) Control	5	6
2) 55, 69, 83	11	19	2) 57, 71, 85, 98	7	6
3) 41, 55, 69, 83	10	19	3) 33, 57, 71, 85, 98	6	2
4) 0, 55, 69, 83	14	10	4) 0, 57, 71, 85, 98	5	3
5) 0, 41, 55, 69, 83	13	10	5) 0 (2x), 57, 71, 85, 98	8	12
			6) 0, 33, 57, 71, 85, 98	4	3
	ns	ns		ns	ns

[a] Application dates in days after planting (DAP): 0 = In-furrow at planting; 0 (2x) = double rate (2.2 kg a.i./ha) applied in-furrow.
[b] Populations at planting and [c]harvest are an average of 5 replications (n = 5).
[d] ns indicates no significant difference between any of the treatments.

2002 Field Season: Untreated plots and those treated on 64, 79, and 94 DAP; or 0, 64, 79, and 94 DAP were sampled on 21 May; 4, 21 June; 1, 9, 16, 24 July; 1, 8, 15, 23, 29 August; and 9, 17 September.

2003 Field Season: Untreated plots and those treated on 56 DAP or 0 and 56 DAP were sampled on 22 May; 22; 23 June; 8, 15, 23, 29 July; 1, 7, 18, 26 August; and 5, 12, 22 September.

2004 Field Season: Untreated plots and those treated on 0, 55, 69, and 83 DAP or 0, 41, 55, 69, and 83 DAP were sampled on 26 May; 6, 16, 23, 27, 30 July; 2, 5, 13, 20 August; 2, 8, 21 September; and 7 October.

Nematode densities were adjusted for soil moisture to convert to densities/250 g dry soil and populations at planting and harvest were transformed to $\log_{10}(x + 1)$ before analysis (ANOVA) to test for differences between treatments. Means of transformed values were back transformed before reporting and Duncan's multiple range test was used to separate means only when ANOVA was significant at $P \leq 0.05$. A T-test was used to compare nematode densities at planting and harvest from the same treatment.

Initial nematode densities in population dynamics samples varied substantially between plots within treatments as well as across treatments. Therefore, densities were normalized to a relative density by dividing population numbers for each sample date by the starting population in that plot.

Effects of oxamyl on symptoms of CRS: Samples of 25 randomly chosen 110 to 340 g cv. Yukon Gold tubers were selected for CRS evaluation from each plot at harvest (2004-2005). Each tuber was peeled and cut into 1.3-cm-thick (55 g) transverse slices for inspection of symptoms of CRS. Only spots or arcs exceeding 0.3 cm diam. were counted. Tubers were placed into categories of 'no damage', 0 percent waste; 'acceptable damage', 1-5 percent waste (up to 1 spot or arc per 55 g of tuber); 'serious damage', 6-10 percent waste (1-2 spots or arcs per 55 g of tuber); and 'culls', over 10 percent waste. Tubers with up to 5 percent waste may be considered as U.S. No. 1 grade and tubers with 5-10 percent waste may be considered U.S. No. 2 grade according to USDA grade standards (USDA, 1991).

Data Analysis: All percent CRS data were transformed to arcsin square root (x) and examined by analysis of variance (ANOVA). Means of transformed values were back transformed before reporting and Duncan's multiple range test was used to separate means only when ANOVA was significant at $P \leq 0.05$. Treatments in 2004 were paired with the comparable treatments in 2005 and analyzed together as a split-plot design with time as the main plot and treatments as the sub-plot. Slight differences in application timing occurred between the two years. The early post-emergence application occurred 8 days earlier (33 DAP) in 2005 compared to 2004 (41 DAP) due to a heavy precipitation event the night before the intended application date in 2004. All treatments receiving oxamyl in 2005 had a final application at 98 DAP compared to a final application at 83 DAP in 2004. The additional application in 2005 was based on higher CRKN densities compared to those observed in 2004. Since immature tubers are highly prone to CRS (Weingartner et al., 1975), it was decided that the additional application at 98 DAP in 2005 would not have influenced CRS expression more than was present at 83 DAP. All other treatment application timings within each year occurred within two DAP from one another. There were no statistical interactions between year and treatment, which suggests this pairing was valid.

Results

Effects of oxamyl on population densities and dynamics of P. allius: Initial population densities of *P. allius* were low and similar (4-6/250 g soil) in 2002, 2003, and 2005, but slightly higher (12/250 g soil) in 2004 (Table 1). Population densities at harvest were not different from those at planting for any treatment in any year. There was also no effect of treatment on final population densities in any year that suggests applications of oxamyl did not have a lasting effect on *P. allius* in potato.

2002 Field Season: Population densities of *P. allius* in the untreated plots increased and decreased during the first 100 days after planting (DAP) reaching ever-increasing peak densities on 14, 49, 64, and 100 DAP before declining rapidly at the end of the season (Fig 1). With the exception of the treatment with the IF (0 DAP) application on the 64 DAP sample date, population densities in plots treated with oxamyl remained lower than in untreated plots throughout the season. However, population dynamics in the treatment with IF (Trt. 5, Table 1) did not appear to be different from the treatment without IF (Trt. 2, Table 1). Average relative densities for all sample dates after the first chemigation (64 DAP) were 28.6, 7.7, and 8.1 in untreated plots, oxamyl without IF, and oxamyl with IF, respectively.

2003 Field Season: Population densities of *P. allius* in untreated plots increased slightly by 32 DAP, decreased again until 54 DAP and then increased with peaks at 71 and 88 DAP (Fig. 2); *P. allius* then declined rapidly, reached a smaller peak on 113 DAP, and then declined again towards harvest. Except for the treatment with IF on the 96 DAP sample date, population densities remained lower in oxamyl treated plots, but there was no difference between treatments with and without IF. Average relative densities for all sample dates after the chemigation treatment (56 DAP) were 5.8, 1.8 and 3.1 for untreated plots, oxamyl without IF, and oxamyl with IF, respectively.

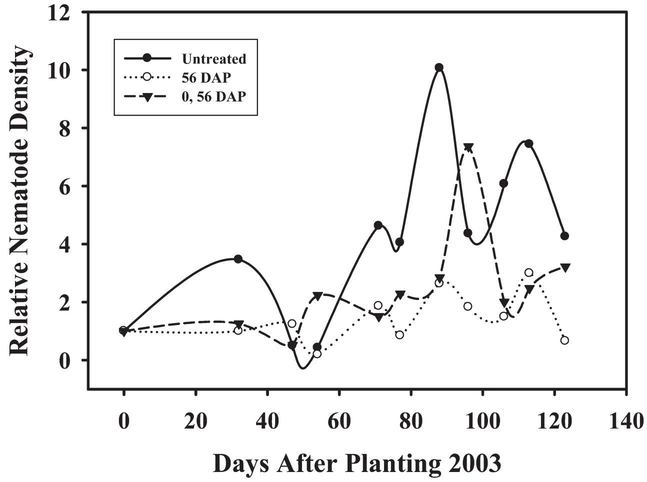

Fig. 2. Effects of oxamyl (1.1 kg a.i./ha) treatments on population dynamics of *Paratrichodorus allius* on potato in the Klamath Basin, OR. 2003. DAP = days after planting at time of application. 0 DAP = in-furrow at planting.

2004 Field Season: Initial population densities of *P. allius* in 2004 were higher than in 2002 and 2003, so there was less relative change in densities through the season. Population densities in untreated plots steadily increased after 65 DAP and did not exhibit cycles of increasing and decreasing numbers as observed in 2002 and 2003 (Fig. 3). IF (Trt. 4 and 5, Table 1) and emergence (Trt. 5, Table 1) applications of oxamyl had no impact on early season population densities and chemigation applications had no apparent effect until after 105 DAP when levels in both oxamyl treatments were lower than in untreated plots. Average relative densities for all sample dates after the first chemigation (41 DAP) were 1.3, 1.4, and 1.6 in untreated plots,

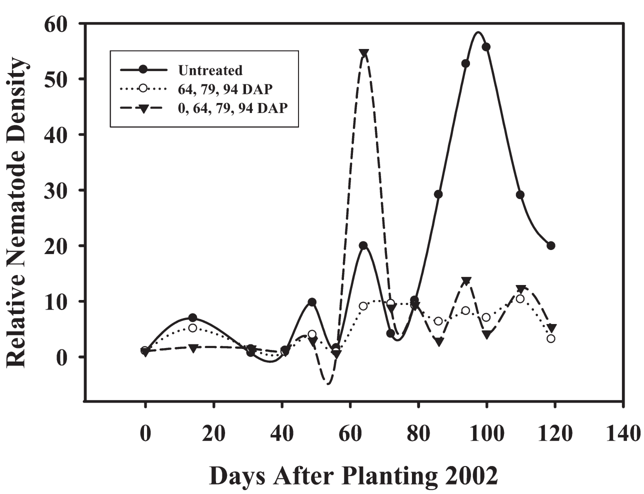

Fig. 1. Effects of oxamyl (1.1 kg a.i./ha) treatments on population dynamics of *Paratrichodorus allius* on potato in the Klamath Basin, OR. 2002. DAP = days after planting at time of application. 0 DAP = in-furrow at planting.

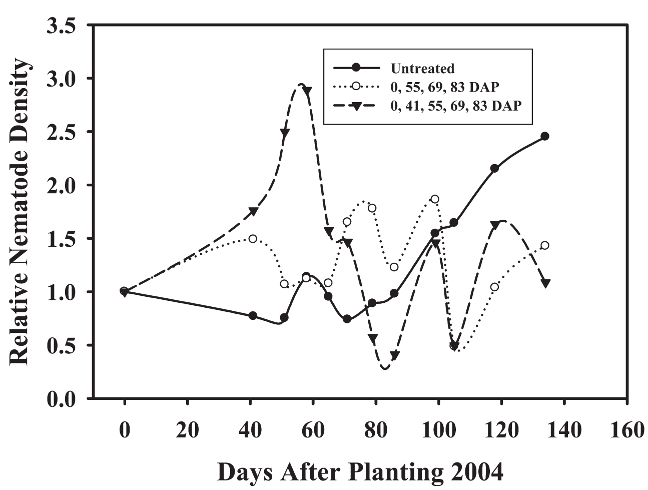

Fig. 3. Effects of oxamyl (1.1 kg a.i./ha) treatments on population dynamics of *Paratrichodorus allius* on potato in the Klamath Basin, OR. 2004. DAP = days after planting at time of application. 0 DAP = in-furrow at planting.

TABLE 2. Effects of oxamyl treatments (1.1 kg a.i./ha) on percentage of Yukon Gold potato tubers expressing symptoms of corky ringspot (CRS), Klamath Falls, OR, 2004.

Treatment[a]	CRS Damage[b]				>5 %[c]	Any
	0	1-5 %	6-10 %	>10 %		
1) Control	53 b[d]	13	7 a	24 a	33 a	47 a
2) 55, 69, 83	65 b	7	3 a	15 ab	18 ab	35 a
3) 41, 55, 69, 83	83 a	7	2 ab	4 bc	9 b	17 b
4) 0, 55, 69, 83	91 a	2	4 a	1 c	6 bc	9 b
5) 0, 41, 55, 69, 83	92 a	8	0 b	0 c	0 c	8 b
Mean	79	7	2	6	10	21

[a] Application dates in days after planting (DAP): 0 DAP indicates in-furrow application.
[b] Percentage of tubers with 1-5% damage would still be considered U.S. No. 1 grade; 6-10% damage would be considered U.S. No. 2 grade; >10% damage would be considered culls.
[c] >5 % is a more sensitive evaluation that includes the percentage of all devalued tubers.
[d] Means within the same column followed by the same letter are not significantly different ($P < 0.05$). Columns devoid of letters indicate no significant differences between any of the treatments.
Reported values may not add to 100% from respective columns (1-5 %, 6-10 %, etc.) based on number transformations and rounding.

oxamyl without an emergence application, and oxamyl with an emergence application, respectively.

Effects of treatment on symptoms of corky ringspot: Yukon Gold tubers infected with TRV expressed classical necrotic arcs, rings, and diffuse brown spot symptoms associated with CRS. Symptom expression was more severe in 2004 (Table 2) than in 2005 (Table 3). Across all treatments, tubers expressing any CRS symptoms averaged 21 percent in 2004 compared to 4 percent in 2005 (Tables 2, 3 and 4). Higher initial populations of *P. allius* may explain the increased symptom expression in 2004 (Table 1). It is also possible that viruliferous nematodes comprised a larger percentage of the initial population in 2004; however, data to confirm this hypothesis were not collected. Tubers usually possessed abundant symptoms (>10%) or no symptoms (zero) in both 2004 (Table 2) and 2005 (Table 3). Relatively few tubers had light symptoms, so there were no significant differences among treatments for tubers expressing 1–5 % CRS damage (U.S. No. 1's) as summarized in Table 4. Therefore, most symptomatic tubers had greater than 5 % CRS damage and were more likely to be graded as culls (>10 %) than as U.S. No. 2's (6–10 %) as shown in Tables 2 and 3.

Oxamyl treatments that began at 55 DAP or later (Trt. 2) did not control CRS and were not significantly different than the untreated control (Tables 2–4). All other treatments (Trt. 3, 4, 5, 6) significantly reduced CRS expression (Tables 2 and 3). Averaged over both years, treatments receiving an early post-emergence application (Trt. 3) had 2 % U.S. No. 2 grade and 1% culls while those receiving both in-furrow and early post-emergence applications (Trt. 5) had no U.S No. 2's or culls due to CRS (Table 4).

DISCUSSION

The effects of oxamyl on CRS were similar to those observed by Weingartner et al. (1981 unpublished data; http://ufdcweb1.uflib.ufl.edu/ufdc/?b=UF00076382&v=00001) in Florida where incidence of CRS when oxamyl was applied at 45, 55, 65, and 76 DAP (65%) was no different from untreated plots (74%). However,

TABLE 3. Effects of oxamyl treatments (1.1 kg a.i./ha) on percentage of Yukon Gold potato tubers expressing symptoms of corky ringspot (CRS), Klamath Falls, OR, 2005.

Treatment[a]	CRS Damage[b]				>5 %[c]	Any
	0	1-5 %	6-10 %	>10 %		
1) Control	82 c[d]	5	1	9 a	12 a	18 a
2) 57, 71, 83, 98	91 bc	1	1	4 ab	6 b	9 ab
3) 33, 57, 71, 83, 98	97 ab	1	1	0 c	1 bc	3 bc
4) 0, 57, 71, 83, 98	99 a	1	0	0 c	1 c	1 c
5) 0, 33, 57, 71, 83, 98	99 a	1	0	0 c	2 bc	1 c
6) 0 (2X), 57, 71, 83, 98	99 a	0	0	1 bc	1 c	1 c
Mean	96	1	0	1	2	4

[a] Application dates in days after planting (DAP): 0 DAP indicates in-furrow application; 33 DAP occurred post-emergence; remaining DAP dates occurred at near two-week intervals thereafter; 0 (2X) indicates a doubled rate of 2.2 kg a.i./ha applied in-furrow.
[b] Percentage of tubers with 1-5% damage would still be considered U.S. No. 1 grade; 6-10% damage would be considered U.S. No. 2 grade; >10% damage would be considered culls.
[c] >5 % is a more sensitive evaluation that includes the percentage of all devalued tubers.
[d] Means within the same column followed by the same letter are not significantly different ($P < 0.05$). Columns devoid of letters indicate no significant differences between any of the treatments.
Reported values may not add to 100% from respective columns (1-5 %, 6-10 %, etc.) based on number transformations and rounding.

TABLE 4. Effects of oxamyl treatments (1.1 kg a.i./ha) on percentage of Yukon Gold potato tubers expressing symptoms of corky ringspot (CRS), Klamath Falls, OR, 2004 - 2005.

	CRS Damage[a]					
	0	1-5 %	6-10 %	>10 %	>5 %[b]	Any
Year Main Effect						
2004	79 b[d]	7 a	2 a	6	10 a	21 a
2005	95 a	1 b	0 b	1	3 b	5 b
CV(%)	16	74	83	115	72	57
Treatment[c] Main Effect						
1) Control	69 b	8	3 a	16 a	22 a	31 a
2) 55/57 DAP + 2 wk intervals	79 b	4	2 ab	8 a	12 b	21 a
3) 33/41 DAP + Trt. 2	92 a	3	2 a	1 b	4 c	8 b
4) 0 DAP + Trt. 2	96 a	1	1 ab	0 b	2 cb	4 b
5) 0 DAP + Trt. 3	96 a	3	0 b	0 b	0 d	4 b
Grand Mean	88	4	1	3	6	12
Sign of Yr-Trt Interaction	ns	ns	ns	ns	ns	ns

[a] Percentage of tubers with 1-5% damage would still be considered U.S. No. 1 grade; 6-10% damage would be considered U.S. No. 2 grade; >10% damage would be considered culls.
[b] >5 % is a more sensitive evaluation that includes the percentage of all devalued tubers.
[c] Application dates in days after planting (DAP): 0 DAP indicates in-furrow application; 33 and 41 DAP occurred post-emergence; remaining DAP dates occurred at near two-week intervals thereafter.
[d] Means within the same column followed by the same letter are not significantly different (P < 0.05). Columns devoid of letters indicate no significant differences between any of the treatments. Reported values may not add to 100% from respective columns (1-5 %, 6-10 %, etc.) based on number transformations and rounding.

incidence of CRS was significantly less when oxamyl was applied early at 35, 45, 55 DAP (35%), or at 0, 35, and 45 DAP (8%). Results from the aforementioned Weingartner study and the current one support other research (Weingartner et al., 1975) which suggests that newly formed tubers are vulnerable to TRV infection. Therefore, oxamyl applications must be made early in the growing season to effectively control CRS. However, decline in *P. allius* population densities after early season applications of oxamyl was not observed in three years of monitoring population dynamics and oxamyl had no effect on numbers of *P. allius* at harvest in four years of study. These observations support prior findings by Alphey (1978) where foliar applications of oxamyl did not reduce trichodorid nematode numbers compared to an untreated check in pot studies. The effects of oxamyl on *P. allius*, when evident, appeared to be in suppressing population density increases rather than reducing existing population densities. Densities that persisted after treatment were sufficient to contribute to CRS in other studies (Ingham et al., 2000; Mojtahedi and Santo, 1999). Therefore, the effects of oxamyl in controlling CRS are more likely due to its nematostatic properties that affect feeding behavior than to nematicidal activity on nematode mortality.

One hypothesis to explain these results is that concentrations of oxamyl in the soil solution from early applications permanently inhibited feeding by over-wintering adult *P. allius* so no TRV was vectored into roots of the young potato plants. However, adults may have had enough stored reserves to lay eggs and the resulting offspring fed but did not harbor TRV nor did they acquire it from the potato. Oxamyl may also have inhibited feeding by over-wintering juveniles but permitted continued biological development, including molting, so that when feeding resumed, they no longer possessed the virus. *Paratrichodorus allius* molts several times during its life cycle and viruliferous nematodes shed TRV with each molt (Ayala and Allen, 1968). Alternatively, oxamyl concentrations in the soil solution may have inhibited nematode feeding temporarily and once feeding resumed the virus did not translocate to the tubers or symptom development did not occur. The later would agree with results from Weingartner et al. (1975), which suggest that TRV transmission occurs through potato tubers during tuberization when skin periderm is very tender. Thus, there may be a suspension of infectivity with early applications that coincides with the period when *P. allius* feeds directly on young tubers during the period of the tubers' greatest susceptibility to infection by TRV. This could explain why oxamyl applications beginning after 55 DAP did not reduce CRS since the majority of virus transmission would have already occurred. Unpublished data from Mojtahedi (personal communication) demonstrated that cvs. Russet Norkotah and Russet Burbank resisted CRS expression after approximately 108 and 150 DAP, respectively. In addition, nematode feeding preference or physical difficulties with stylet penetration may occur as tuber periderm thickens and hardens which restricts feeding to roots rather than tubers. Additional research is needed to verify these hypotheses. Regardless of the mechanism, oxamyl can provide good control of CRS in potato tubers if applied early in the season and is an effective treatment in production regions where fumigation alone is ineffective or not commonly used such as the Klamath Basin, San Luis Valley of Colorado, and the Midwest U.S.

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