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Effects of Soil Fumigants and Aldicarb on Corky Ringspot Disease and Trichodorid Nematodes in Potato[1]

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Abstract: In 1982 and 1983 the soil fumigants ethylene dibromide (EDB), EDB + chloropicrin, and 1,3-dichloropropene (1,3-D) applied with one or three chisels per row were evaluated singly and in combination with aldicarb on potato, *Solanum tuberosum* cvs. Atlantic and Sebago, for control of trichodorid nematodes and potato corky ringspot disease (CRS). In 1982 dosages per chisel for EDB, EDB + chloropicrin, and 1,3-D were 16.8, 23.9, and 56.1 liters/ha, respectively. EDB was applied at 12.6 liters per chisel per ha in 1983. Aldicarb was applied at 3.4 kg a.i./ha in-the-row. Differences ($P \leq 0.05$) in the percentages of tubers having CRS and in mean trichodorid population densities were recorded between methods of fumigant application and among fumigants. The reductions in CRS associated with triple-chisel applications compared with single-chisel applications of the fumigants were insufficient to justify their commercial use solely for CRS control. Addition of aldicarb to all fumigation treatments, regardless of the fumigant application method, resulted in highly effective control of CRS. The disease was less severe in Atlantic; however, CRS was sufficiently severe to justify use of aldicarb on either cultivar.

Key words: aldicarb, corky ringspot, crop loss, ethylene dibromide (EDB), 1,3-dichloropropene (1,3-D), *Paratrichodorus minor,* potato, soil fumigation, *Solanum tuberosum,* stubby-root nematode, *Trichodorus* spp.

Approximately one-third of the 10,000 ha of potato (*Solanum tuberosum* L.) in northeast Florida are affected to some extent by corky ringspot disease (CRS), which is vectored by trichodorid nematodes (10,15). Although effective elsewhere (2,3,5,6), preplant soil fumigation has failed to control CRS in this region because trichodorid nematodes migrate upward from deeper soil into treated soil after the fumigant has dissipated (15). Certain nonvolatile nematicides, particularly aldicarb, when applied alone or in combination with soil fumigants, have been highly effective in controlling CRS (14,15). Aldicarb is presently used alone or in combination with a soil fumigant on > 95% of the potato hectarage in Florida (14).

Trichodorid nematodes are part of a complex pathosystem in Florida. Nematode species in 13 genera are found frequently in potato fields, and bacterial wilt caused by soil-borne *Pseudomonas solanacearum* E. F. Smith has been severe in recent seasons (13–16). A nematode-disease management program for potato which includes aldicarb, soil fumigants, and different potato cultivars has been developed (16).

Northeast Florida farmers use a ridged-row seepage irrigation system (1,4,9) which is particularly suited to in-row applications of nematicides. Well-defined rows are maintained throughout the season, enabling growers to place the chemicals precisely where the crop will be grown.

Because of the practicality, nematicidal efficacy (14,15), and relatively low cost associated with in-row use of nematicides, broadcast use of fumigants for potato production has not been studied previously. The failure of soil fumigants to control CRS (15) prompted the research reported here. Our objectives were 1) to compare trichodorid nematode and CRS control by standard in-row dosages of fumigants applied with a single chisel per row alone and in combination with aldicarb, and by the use of simulated broadcast treatments applied with three chisels per row; and 2) to compare the efficacy of the nematicides on Atlantic and Sebago potato cultivars.

MATERIALS AND METHODS

Test site: Separate experiments were performed in 1982 and 1983 in a 0.32-ha field

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monocultured to potatoes with a summer cover crop of sorghum-sudangrass (*Sorghum bicolor* (L.) Moench × *S. arundinaceum* (Desv.) Stapf var. *sudanense* (Stapf) Hitchc.) for > 20 years. The soil was an Ellzey fine sand (sandy, siliceous, hyperthermic Arenic Ochraqualf) having approximately 91.7% sand, 5.6% silt, 2.7% clay; pH 5.5–6.0 (8). The field contained *Belonolaimus longicaudatus* Rau, *Meloidogyne incognita* (Kofoid and White) Chitwood, trichodorids (mixed populations of *Paratrichodorus minor* (Colbran) Siddiqui, *Trichodorus viruliferous* Hooper, and *T. proximus* Allen) and several additional genera of phytoparasitic nematodes (11). In addition, both CRS and bacterial wilt occurred in the field, although their relative severity varied considerably from season to season.

Plot design: Both experiments had six replications of all treatment combinations. The treatments were two methods of application (one or three chisels per row), two cultivars (Atlantic and Sebago), three soil fumigants (ethylene dibromide [EDB], 54% EDB + 45% chloropicrin, and 1,3 dichloropropene [1,3-D]), and a granular nematicide (+ or − aldicarb). Methods of application, soil fumigants, and aldicarb treatments were applied in a three-level split-plot design with application methods as main plots, soil fumigants as subplots, and aldicarb as sub-subplots. In order to facilitate mechanical planting, varieties were planted in two-row strips lengthwise across all other treatments. The overall design for analyses of variance was treated as a three-level split-plot coupled with a split-strip (Table 1).

The sub-subplots were four rows wide, spaced 1.0 m apart, and consisted of two rows of each cultivar. Cultivars were planted adjacent to each other so that the center two rows (i.e., data rows) of each sub-subplot consisted of one row of each cultivar. Sub-subplots were 7.6 m long.

Method of application: Fumigants were applied with either a single chisel per row (the standard application method) or three chisels per row (to simulate broadcast application). The single-chisel applications were made 25–30 cm deep in the center of the row. The center chisel of the three-chisel treatment was similarly placed, with the lateral chisels spaced 13 cm to each side of the center and 5–7 cm deeper. All chisel slits were closed with a floating chain and bar following immediately behind the chisels. Following fumigation, the ridged rows were reshaped using bedding disks; they remained in this condition until planting time.

Soil fumigants: Plots were fumigated 27 January and 2 December 1982, respectively, for the 1982 and 1983 experiments. The fumigant rates applied through each chisel in the 1982 experiment were EDB, 16.8 liters/ha (52 ml per chisel per 30.5 m); 54% EDB + 45% chloropicrin, 23.9 liters/ha (74 ml per chisel per 30.5 m); and 1,3-D, 56.1 liters/ha (174 ml per chisel per 30.5 m). Rates during 1983 were the same except that EDB was applied at 12.6 liters/ha (39 ml per chisel per 30.5 m).

Aldicarb and potato varieties: Planting furrows were opened and potato seed pieces were dropped by machine on 12 February 1982 and 16 February 1983. Seed tubers in the center rows (one row of each variety) were placed manually at a spacing of 20 cm. Aldicarb was applied in a 25-cm band over the seed pieces at a rate of 3.4 kg a.i./ha (10.4 g/30.5 m of row). Rows were closed with bedding disks following application of aldicarb.

Cultural practices: Except for the soil fumigation treatments, routine growing practices and pest control procedures for northeast Florida were used in both experiments. A fertilizer mixture of NH_4PO_4, NH_4NO_3, and urea providing 150 kg N and 196 kg P_2O_5/ha was banded at planting on both sides of the row just beneath the seed pieces. Metribuzin for preemergent weed control was applied at 0.6 kg a.i./ha overall. Captan 7D (0.45 kg/45.4 kg cut seed) was used to prevent seed piece decay. Standard rates of mancozeb or chlorothalonil were applied weekly to manage early and late blight.

Soil samples: Soil samples for nematode assay were taken on 5 May 1982 and on 31 May–1 June 1983. Ten soil cores (each 2.5 cm d × 20–25 cm deep) were taken from

TABLE 1. Analysis of variance for percentage of tubers with corky ringspot (CRS), severity of CRS, and trichodorid nematode populations following treatment of Atlantic and Sebago potatoes with single- or triple-chisel injections of soil fumigants used singly or in combinations with aldicarb.

		Mean squares ($\times 10^{-3}$)				Mean squares ($\times 10^{2}$)	
		1982			1983	1983	
Source of variation	df	Tubers with CRS (%)	Severity of CRS	Trichodorid nematodes	Tubers with CRS (%)	df†	Trichodorid nematodes†
Replications	5	43	1,320*	6,595	140	5	171
No. chisels/row (C)	1	108	11,000**	46,115*	39	1	27
Error a	5	66	260	3,594	39	(5)	157
Variety (V)	1	140	461,530**	30,042*	3,649**	—	—
Error b	5	60	900	4,459	22	—	—
V × C	1	30	4,070	71	90	—	—
Error c	5	25	1,360	4,454	51	—	—
Fumigant (F)	2	160*	290	9,434**	246*	2	166
F × C	2	160*	1,020	7,111**	329**	2	278
F × V	2	66	1,920*	1,000	27	—	—
F × C × V	2	47	920	1,375	52	—	—
Error d	40	46	585	1,258	53	(20)	181
Nematicide (N)	1	11,830**	349,070**	283,053**	10,126**	1	28,512**
N × C	1	547**	6,160	9,025	34	1	239
N × V	1	299**	288,430**	24,548**	1,833**	—	—
N × F	2	39	10	3,671	150*	2	109
N × C × V	1	1	1,410	656	65	—	—
N × C × F	2	52	760	949	263**	2	250
N × V × F	2	89	410	857	108	—	—
N × C × V × F	2	16	100	238	32	—	—
Error e	60	4	689	2,374	38	(30)	152

Prior to analysis of variance, the proportion of tubers with CRS and numbers of nematodes were transformed to arcsine values and $\sqrt{\text{nematodes} + 1}$, respectively. CRS severity values (1–10) were not transformed.

† Soil samples from individual variety rows were bulked during 1983, changing the design for analysis of variance and the degrees of freedom for trichodorid numbers. Degree of freedom values in ( ) are, from top to bottom, error terms a, b, and c, respectively. Dashes (—) indicate terms not present in analysis of trichodorid numbers. *, ** = $P \leq 0.05$ and 0.01, respectively.

the rhizosphere within each data row of each plot. The soil samples of the individual rows were processed separately in 1982, whereas in 1983 the center two rows were bulked and processed as a composite. Nematodes were extracted from 100-cm³ aliquants using a modification of the sugar-centrifugation method (7).

Tuber yields and CRS determinations: Potatoes were mechanically harvested, washed, graded, and weighed on 26 May 1982 and on 2–3 June 1983. As tubers passed across a grading table, severity of CRS was rated visually in 1982 on a scale of 1–10 with 1 being all tubers completely free of defects and 10 being 100% of the surface of all tubers affected. Severity was not rated in 1983. Following grading, 20 tuber subsamples were taken from U.S. Size A tubers (> 4.75-cm-d) for determination of incidence of CRS. Presence of typical CRS lesions on the surface of Sebago tubers was scored as positive CRS. Because Atlantic tubers do not exhibit typical CRS lesions, they were sliced and diagnosis of CRS was based on the presence of typical internal necrosis.

Statistical analysis: All data were subjected to analysis of variance (Table 1). Nematode data were transformed by $\sqrt{n + 1}$ and CRS incidence converted to proportions and arscine-transformed prior to ANOVA. Mean separations were calculated using transformed data and grouping designations were affixed to untransformed data. All mean separations are expressed at $P \leq 0.05$.

RESULTS

Percentage of tubers with corky ringspot disease: Analysis of variance indicated numerous significant ($P \leq 0.05$) effects on

TABLE 2. U.S. Size A tubers with corky ringspot disease (CRS) as affected by different fumigants and application methods used singly or in combination with aldicarb in 1982 and 1983.

	Tubers with CRS (%)			
	1982		1983	
Nematicide treatment†	One chisel	Three chisels	One chisel	Three chisels
EDB				
+ aldicarb	8.5 a	21.5 a	2.9 ab	2.9 ab
− aldicarb	68.0 a	58.0 a	35.4 c	54.2 d
EDB chisel means	38.3 yz	39.8 z	19.0 y	28.5 z
EDB means	39.0 n		23.8 n	
EDB + chloropicrin (Pic)				
+ aldicarb	9.0 a	13.0 a	1.7 a	3.4 ab
− aldicarb	62.0 a	41.5 a	41.3 c	32.1 c
EDB + Pic chisel means	35.5 x–z	27.3 xy	21.5 yz	17.5 y
EDB + Pic means	31.4 m		19.5 mn	
1,3-D				
+ aldicarb	8.0 a	5.0 a	1.3 a	0.4 a
− aldicarb	65.0 a	46.0 a	41.3 c	15.4 b
1,3-D chisel means	36.5 yz	25.5 x	21.3 yz	8.0 x
1,3-D means	31.0 m		14.8 m	
Overall chisel means	36.7 p	30.8 p	20.6 p	18.0 p

Data are averaged across cultivars. Values based on presence or absence of CRS in 20 randomly selected U.S. Size A tubers from each plot. Values within a treatment level (fumigant [m–n], chisel [p–q], fumigant × number of chisels [x–z], number of chisels × fumigant × aldicarb [a–d]) during an individual year followed by the same letter do not differ significantly ($P = 0.05$) according to Duncan's multiple-range test.

† Respective rates per chisel of EDB, EDB + Pic, and 1,3-D in 1982 were 16.8, 23.9, and 56.1 liters/ha. Rates per chisel in 1983 were the same, except for EDB which was applied at 12.6 liters/ha.

severity of CRS in both seasons (Table 1). The overall incidence of CRS was greater in 1982 than in 1983 (Tables 2, 3). However, effects of the different treatments on the percentage of tubers with CRS were similar in both years. Varying the number of chisels used to apply the fumigants failed to reduce the incidence of CRS during either year (chisel means, Table 3). The percentage of CRS in Atlantic was numerically less than in Sebago both seasons (Table 3); however, the difference was significant ($P \leq 0.05$) only in 1983. There were significant differences among fumigants in percentage of tubers having CRS in both years (Table 2). In both years, tubers from EDB-

TABLE 3. U.S. Size A tubers with corky ringspot disease (CRS) as affected by application method, variety, and aldicarb in 1982 and 1983.

	Tubers with CRS (%)				
Aldicarb treatment	One chisel	Three chisels	Atlantic	Sebago	Aldicarb means
			1982		
+ aldicarb	8.4 a	13.1 a	11.4 x	10.0 x	10.7 m
− aldicarb	65.0 c	48.5 b	49.8 y	63.8 z	56.8 n
Means	36.7 m	30.8 m	30.6 m	36.9 m	
			1983		
+ aldicarb	2.0 a	2.2 a	0.5 x	3.8 x	2.1 m
− aldicarb	39.3 a	33.9 a	15.3 y	58.0 z	36.6 n
Means	20.6 m	18.0 m	7.9 m	30.9 n	

Data are averaged across fumigants. Values based on presence or absence of CRS in 20 randomly selected U.S. Size A tubers from each plot. Values within each level (application method × aldicarb [a–d], variety × aldicarb [x–z]) during an individual year followed by the same letter do not differ significantly ($P = 0.05$) according to Duncan's multiple-range test. Paired means for aldicarb, application method, or variety followed by the same letter (m, n) do not differ significantly ($P = 0.05$).

treated plots had more CRS than those from plots treated with the other fumigants. Use of aldicarb resulted in 81.2% and 94.5% reductions in percentage of CRS in 1982 and 1983, respectively (Table 3).

Several treatment interactions were observed in addition to the main effects presented above. A significant fumigant × number of chisels interaction occurred both years (Table 2). This was primarily a result of the percentage of CRS being lower from the triple-chisel 1,3-D plots than from those of the other fumigants and the single-chisel 1,3-D plots. Also, in 1983 an increase in CRS from EDB-treated plots was associated with the triple-chisel compared with the single-chisel application. The aldicarb × number of chisels interaction in 1982 (Table 3) and the aldicarb × number of chisels × fumigant interaction in 1983 (Table 2) both resulted from the superimposed aldicarb treatment negating the differences in CRS associated with the single-chisel and triple-chisel applications of fumigants. The range in percentage of CRS varied more widely in nonaldicarb plots than in those treated with the chemical. The percentage of CRS in 1983 in fumigated plots not treated with aldicarb varied from 15.4% in the triple-chisel 1,3-D plots to 54.2% in those with EDB. Plots similarly fumigated plus being treated with aldicarb, on the other hand, varied from 0.4% CRS in triple-chisel 1,3-D to 3.4% in triple-chisel EDB + chloropicrin plots. There was also a soil fumigant × aldicarb interaction in 1983. Respective percentages of CRS in EDB, EDB + chloropicrin, and 1,3-D plots were 48.7, 36.7, and 24.4%. Following application of aldicarb, respective percentages of CRS were 2.9, 2.6, and 0.7% (data computed from Table 2).

Percentage of CRS was also affected by a nematicide × variety interaction during both seasons. Sebago tubers in the absence of aldicarb had more CRS than did Atlantic tubers. Use of aldicarb mitigated the difference between varieties (Table 3). In 1982 the relationship of the percentage of CRS in Sebago tubers to population densities of trichodorid nematodes was described by the linear equation: CRS = 1.64 + 0.287 trichodorids (r^2 = 39.7%, $P \leq 0.0001$).

Severity of CRS: Severity ratings of CRS in 1982 ranged from 1.0 in aldicarb-treated Atlantic to 8.7 in Sebago treated with EDB + chloropicrin applied with a single chisel. Generally, the severity of CRS followed the same trend as percentage of CRS (Table 1) and therefore the data are not shown. Severity of CRS was reduced following the triple-chisel applications of fumigants, use of aldicarb, and the use of Atlantic. As above, use of aldicarb negated differences in severity observed among dosages of fumigants and between cultivars. Differences in aldicarb usage and cultivars had greater effects on severity ratings than did differences in application methods or fumigants. Tubers from plots treated with aldicarb had average ratings of 1.4, whereas those from plots without aldicarb averaged 4.7. Average ratings in Sebago were 4.7, compared with 1.1 in Atlantic. The relationship of CRS severity in Sebago to populations of trichodorid nematodes in 1982 was described by the equation: CRS = 1.54 + 0.904 trichodrids (r^2 = 51.7%, $P \leq 0.0001$).

Nematode population densities: Significant main effects of chisel number (Tables 1, 4), cultivars (Tables 1, 5), fumigants (Tables 1, 4), and aldicarb usage (Tables 1, 5) on at-harvest population densities of trichodorid nematodes were observed in 1982. Fewer ($P \leq 0.05$) nematodes were present in plots with EDB or EDB + chloropicrin than in plots with 1,3-D (Table 4). Increasing the number of chisels (Table 4) and applications of aldicarb (Table 5) resulted in lower nematode populations. Populations were lower in plots with Atlantic than in plots with Sebago. A significant fumigant × number of chisels interaction occurred wherein relative populations in the triple-chisel EDB and EDB + chloropicrin plots tended to be much lower with regard to their respective single-chisel applications than was the case with the triple-chisel and single-chisel applications of 1,3-D (Table 4).

TABLE 4. Population densities of trichodorid nematodes following different fumigation treatments.

Fumigant†	Nematodes/100 cm³ soil		
	One chisel	Three chisels	Fumigant means
	1982		
EDB	19 b	6 a	13 m
EDB + chloropicrin	15 ab	6 a	11 m
1,3-D	20 b	15 ab	18 n
Chisel means	18 y	9 x	
	1983		
EDB	17 a	15 a	16 m
EDB + chloropicrin	23 a	21 a	22 m
1,3-D	16 a	26 a	21 m
Chisel means	19 x	21 x	

Data are averaged across aldicarb and variety treatments. Values within a treatment level (application method [x–y], fumigant [m–n], application method × fumigant [a–b]) in one year followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.

† Respective rates per chisel of EDB, EDB + chloropicrin, and 1,3-D in 1982 were 16.8, 23.9, and 56.1 liters/ha. Rates per chisel in 1983 were the same, except for EDB which was applied at 12.6 liters/ha.

The relative densities of trichodorid nematodes following the various treatments in 1983 were similar to those of 1982. The only significant ($P \leq 0.05$) effect of treatments in 1983 was the lesser density in aldicarb-treated plots than in those not treated (Table 5).

Economic losses due to CRS: Precise determination of economic losses due to CRS is difficult because the percentage of CRS-affected tubers culled or the effect on price depends upon the severity of infection. Many superficially affected tubers can be salvaged for potato chip production. Based on our experience, however, a reasonable estimate of losses due to culling would be 25% of CRS-affected tubers. Applying this percentage to CRS data in Table 3 and using yield and economic data from Weingartner and Shumaker (11), losses of $18 to $491/ha were sustained due to CRS in 1982 and 1983 (Table 6). Use of aldicarb reduced losses by $389 and $232/ha, respectively, in 1982 and 1983.

TABLE 5. Population densities of trichodorid nematodes for aldicarb treated and untreated Atlantic and Sebago potatoes.

	Aldicarb		Variety means
	+	−	
	1982		
Atlantic	3 a	15 b	9 m
Sebago	4 a	32 c	18 n
Aldicarb means	4 x	24 y	
	1983		
Aldicarb means†	4 x	36 y	

Data are averaged across fumigants and application methods. Values within a treatment level (variety [m–n], aldicarb [x–y], variety × aldicarb [a–c]) during an individual year followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.

† Soil samples from individual cultivar rows were bulked in 1983.

TABLE 6. Comparison of economic losses during 1982 and 1983 due to corky ringspot disease (CRS) in aldicarb treated and untreated plots.

	Tuber yield (mt/ha)		Loss in yield due to CRS (mt/ha)		$ loss/ha†	
	1982	1983	1982	1983	1982	1983
+ aldicarb	29.0	24.1	0.78	0.13	102	18
− aldicarb	26.3	19.3	3.74	1.77	491	250

Data averaged across all fumigation and cultivar treatments. Twenty-five percent of tubers having CRS symptoms (Tables 2, 3) were assumed to be nonmarketable.

† $ loss/ha = mt/ha lost to CRS × crop value of $131.22/mt in 1982 and $140.96/mt in 1983, rounded to the nearest dollar.

DISCUSSION

Potato corky ringspot disease is one of the most important diseases affecting potatoes in northeast Florida. Even after long rotations to other crops, fields determined to be infested with CRS during the late 1940s still remain infective today. The mechanisms of this persistence have not been determined.

Since 1969, all soil fumigants evaluated in northeast Florida at in-row rates sufficient to control nematodes have failed to control CRS. Additionally, rates of EDB and DD exceeding double the recommended rates for nematode control have not controlled CRS. (All of the fumigants in these experiments were applied using a single injection chisel per row.) Certain nonvolatile nematicides, including oxamyl, carbofuran, ethoprop, and aldicarb, provided economical control of CRS

(14,15,17). Aldicarb provided the most consistent control. Fenamiphos at 3.4 kg a.i./ha was ineffective. Because of the problem of CRS in potato fields and other factors, use of aldicarb at 3.4 kg a.i./ha in-the-row became a standard practice in northeast Florida potato production (14,15).

It was hoped at the onset of these experiments that application of soil fumigants using multiple chisels per row would sufficiently reduce trichodorids in deep soil to provide adequate CRS control. Although the multiple-chisel method provided better control than the single-chisel applications, none of them were equal to aldicarb. Data in these experiments and others performed with metham sodium (12) and methyl bromide further verify that soil fumigation, regardless of the fumigant or dosage used, is ineffective in controlling CRS in northeast Florida. Aldicarb, however, provides outstanding control of the disease and large economic gains are associated with its use in this potato production system.

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