In-Bed Fumigation for Control of Rhizomania of Sugar Beet

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ABSTRACT

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Preplant application of fumigants by single chisel in plant bed centers significantly increased beet and sugar yields of sugar beets 5–6 months old. Products containing dichloropropene were the most effective in controlling rhizomania. In separate studies, application of Telone II at 29.3, 43.9, and 58.6 L/ha raised sugar yields 83–182, 252, and 78–258%, respectively, compared to the control treatments. Vorlex, Vorlex 201, and Pichlor 60 also reduced disease incidence and significantly increased yield when applied at 132.7, 146.1, and 32.7 L/ha, respectively. Sealing the soil with water, although not essential for effective control, significantly increased yield over unsealed treatments with Telone II at 29.3 L/ha and all rates of Vorlex. Although metham-sodium and the low rate of chloropicrin (21.3 L/ha) did not control rhizomania, sugar yields were 42 and 44% greater, respectively, than in control treatments, possibly because other root pathogens were controlled. Protecting plants from infection for the first 9–11 wk after planting appeared to be critical for preventing beet and sugar yield reductions caused by rhizomania.

Rhizomania is a debilitating disease of sugar beet (*Beta vulgaris* L.) caused by beet necrotic yellow vein virus (BNYVV), whose vector is the fungal obligate parasite *Polymyxa betae* Keskin. The disease is widespread in sugar beet production areas of Europe and Japan and has occurred more recently in central California (6). Rhizomania reduces yield significantly, lowers root quality, and predisposes the host to other soilborne pathogens. The common name for the disease, rhizomania, was coined by Canova (3) in 1959 and is descriptive of the symptoms: in advanced stages of disease, growth of the taproot is severely restricted and feeder roots proliferate, giving the impression of root bearding. Yield is reduced because of the absence of a well-developed taproot for sugar storage and because root impurities (e.g., sodium, potassium, and amino nitrates) increase and interfere with sugar extraction during processing. In addition, more soil may adhere to bearded roots, which increases transportation costs and disposal problems at processing facilities.

Currently, there is no economically effective control measure for rhizomania on commercially grown sugar beets in the United States. Resistance to the virus has been identified in a wild beet species (*B. maritima* L.) (14) and in several sugar beet breeding lines (9,15), but high levels of resistance are not yet available in acceptable commercial cultivars in the United States. Crop rotation is ineffective for control because *P. betae* forms long-lived resting spores (cystosori), and many common chenopodiaceous weed species may act as alternate hosts for both the vector and the virus (2,8,15). Several soil fungicides (pyroxychlor, prothiocarb, copper oxychloride, ferrous sulfate, and ethazole) have been evaluated without success for disease control (5).

Soil fumigation has been found to be effective against rhizomania but is not always economically feasible. Methyl bromide controls the fungal vector in the soil (7,13) but is too costly for use in commercial production; furthermore, reinfestation by the vector from adjacent untreated soil may occur within 5–6 wk after planting (E. D. Whitney, *unpublished*). Alghisi and D'Ambra (1) reported that broadcast treatment with dichloropropene may control the disease and increase sugar beet yields significantly. Hess and Schlosser (7) concluded from large-scale field trials in Germany that dichloropropene applied at 150 L/ha controlled disease; however, depending on the severity of the disease, this rate may not be economically feasible for growers to use.

We evaluated the efficacy and cost-effectiveness of in-bed, preplant fumigation treatments for controlling rhizomania. Because of the successful control reported previously with dichloropropene, fumigants containing this compound were compared based on application of equivalent in-bed amounts of dichloropropene. A preliminary report has been published (10).

MATERIALS AND METHODS

Field plots. Trials were conducted at the USDA Agricultural Research Service Research Station in Salinas, CA, in a silty loam soil naturally infested with BNYVV-viruliferous *P. betae*. Before fumigation, the field was rototilled to a depth of 20 cm and formed into raised beds with 70-cm centers. In each study, treatments were replicated four times in a randomized complete block design of two 7-m rows for each replicate. Buffer areas of 1–2 m were located at the end of each treatment block and at the edges of the field. Sprinkler irrigation was provided, with the rows configured in such a way that runoff was prevented from contaminating adjacent treatment areas.

Soil fumigation. Trade names are used for some fumigants because they contain multiple components (Table 1). The following fumigants were evaluated for disease control: Telone II (Dow Chemical, Midland, MI); Vorlex and Vorlex 201 (NOR-AM Chemical Company, Wilmington, DE); Pichlor 60, chloropicrin, and methyl bromide (Tri-Cal, Inc., Morgan Hill, CA); and metham-sodium (ICI Americas, Inc., Wilmington, DE).

Fumigants were applied with a single chisel at a depth of 15 cm in the center of the beds. A constant head-flow manifold using gravity flow through disks with specified aperture sizes was used for fumigation. Rates of fumigant applied (Table 1) reflect the total amount of material applied per hectare based on application to the middle of rows with 70-cm centers.

Immediately after fumigant application, the soil was compacted by a roller located behind the chisel applicator. In 1985, all trials were sprinkler-irrigated after fumigation with about 2.5 cm of water in 1.5 hr. In 1986, only half of the replicates were given this treatment in order to evaluate the effect of irrigation on the efficacy of the fumigants. In 1987, the methyl bromide treatment was

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The use of trade names does not imply endorsement by the USDA or the University of Florida and does not imply approval to the exclusion of other products not mentioned.

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covered with plastic mulch for 2 days after application, the Telone II treatments were sealed with water, the plots were expanded to four rows, and only the center two rows were harvested.

Planting. The rhizomania-susceptible cultivar US H11 was planted 2 wk after fumigation. Before seeding, the top 2.5 cm of soil was removed with a V-shaped scraper. Several days after planting, a broadcast treatment of Pyramin (3.92 kg a.i./ha) was applied for weed control, and pentachloronitrobenzene (2.86 kg a.i./ha) was applied to control *Rhizoctonia solani* Kühn. Four weeks after planting, plants were thinned to about 15-cm spacing, and 15% granular aldicarb was side-dressed at 5.04 kg a.i./ha for nematode control. Additional cultivation of plants throughout the trials was consistent with commercial cultivation and irrigation practices in the Salinas Valley.

Data collection. In 1985, at 3, 5, 7, 9, 11, and 21 wk after planting, four plants were removed at random from each replicate plot and were bulked into two separate subsamples. Roots were washed to remove adhering soil, and 0.5 g of tissue was homogenized in 2 ml of phosphate-buffered saline at pH 7.4 (4). The presence of BNYVV was assessed by enzyme-linked immunosorbent assays (4).

Plants were harvested 21 wk after planting, and the roots were rated visually for disease on a scale of 0–6: 0 = no visual symptoms; 1 = minor root bearding but taproot not brittle; 2 = taproot moderately constricted, bearded, and brittle; 3 = taproot shaped like a wineglass and brittle, with bearding of feeder roots; 4 = taproot present but severely damaged, heavy bearding of fibrous roots; 5 = severe bearding and stunting, taproot destroyed below the crown (advanced stage of disease, before plant collapse); and 6 = plant dead. The roots were weighed before and after adhering soil particles were washed off; the difference in weight was divided by the unwashed weight and expressed as percent tare, a reflection of the nonprocessible portion (predominantly soil) of the harvested beets.

Data collection in 1986 and 1987 was similar to that in 1985 except that samples were collected less often to assay for the presence of viral infection, and trials were terminated after 22 wk.

Tissue analysis. Root and crown tissue was analyzed for amino nitrates, sodium, and potassium by Inter-Mountain Laboratories (Sheridan, WY), a commercial company specializing in the analysis of sugar beets using procedures developed by Stout (12). Concentrations of sodium and potassium were quantified with a flame photometer, and amino nitrates were assayed using a ninhydrin procedure. A polarimeter and refractometer were used to determine the percentages of sucrose and total solids, respectively, in the liquid phase of filtered brei collected from sawed beets.

All analyses of variance and linear modeling of the data were done with the SAS statistical program (11). Means were considered significantly different when the probability of a greater F value was less than or equal to 0.05. For the 1986 trials, linear and quadratic contrasts were calculated for all data across all rates of the fumigants. When the quadratic components are significant, the linear model is not adequate for predictive purposes because of curvature of the line, but the significance of the linear slope can still be interpreted in terms of overall increase or decrease.

Table 1. Rate of fumigant application and components of each product used in field trials for control of rhizomania on sugar beets

Treatment	Rate[a] (L/ha)	Amount of active ingredient applied (L/ha)		
		Dichloropropene	Methylisothiocyanate	Chloropicrin
		1985		
Metham-sodium	71.7	...	...	...
Telone II	29.3	26.9	...	...
	58.6	53.9	...	...
Vorlex	132.7	53.1	26.5	...
Vorlex 201	146.1	49.0	24.9	21.9
Pichlor 60	37.2	16.2	...	19.4
	66.5	29.0	...	34.7
Chloropicrin	21.3	...	...	21.0
	45.2	...	...	44.8
		1986		
Telone II	29.5	27.1	...	...
	43.9	40.3	...	...
	58.6	53.8	...	...
Vorlex	43.9	17.6	8.8	...
	87.8	35.1	17.5	...
	132.5	53.1	26.5	...
		1987		
Telone II	58.6	53.9	...	...
Methyl bromide[b]	254.5	...	...	84.0

[a]The total amount of fumigant applied per hectare based on application to the center of beds with 70-cm centers. To calculate equivalent broadcast rates with chisel spacing in accordance with manufacturer recommendations for Telone II (30 cm), Vorlex (20 cm), and Vorlex 201 (20 cm), multiply these values by 2.33, 3.5, and 3.5, respectively.

[b]Methyl bromide was applied as a broadcast treatment at a rate of 421.3 kg/ha, and the soil was covered with a plastic mulch after treatment. Volume of application was calculated based on a specific gravity of 1.68 kg/L. With 67% of the product as methyl bromide, its application rate was 168 L/ha.

RESULTS

Effect of fumigation on time of infection and disease rating of roots. The time of root infection by BNYVV and the subsequent disease rating of roots at harvest were positively correlated. In 1985, beets grown in the control, metham-sodium, and low rate of chloropicrin (21.3 L/ha) treatments were infected 3 wk after planting (Table 2) and also had the highest disease ratings (2.2–3.1) (Table 3). Beets treated with Pichlor 60 at 37.2 L/ha or chloropicrin at 45.2 L/ha had no infection or only limited infection until 11 and 9 wk after planting, respectively, and had a low disease rating (0.7). The high rate of Pichlor 60 (66.5 L/ha) delayed infection until between 11 wk and harvest, and roots had negligible levels of disease. A low level of BNYVV infection was detected at harvest for the Vorlex 201 treatment, and the disease rating was low (0.2). Treatments in which no viral infection was detected at harvest (Telone II at 58.6 L/ha and Vorlex at 132.7 L/ha) also had negligible disease ratings.

All rates of Telone II tested had significantly lower disease ratings than untreated controls, and the lowest disease rating was observed at the highest application rate. At 58.6 L/ha with a water seal after fumigation, disease ratings were 0.0, 0.1, and 0.1 in 1985 (Table 3), 1986 (Table 4), and 1987 (Table 4), respectively. At the lowest application rate (29.5 L/ha), disease ratings of 0.5, 0.4, and 1.3 were observed in 1985 (Table 3) and for soil sealed and not sealed with water following fumigation in 1986 (Table 4), respectively. An intermediate rate of 43.9 L/ha was evaluated in 1986 and gave low disease ratings irrespective of postfumigation soil sealing (Table 4).

Beets treated with Vorlex at the two higher rates tested (132.5 and 87.8 L/ha)

had low disease ratings (0.3 or less) (Tables 3 and 4). However, at a lower rate (43.9 L/ha), disease increased significantly (1.8 and 2.1 for sealed and unsealed postfumigation soil treatment, respectively) (Table 4). No disease was detected in the methyl bromide treatment in 1987.

Sealing soil with water after fumigant application did not appear to have any effect on the extent of BNYVV infection 4 wk after planting (Table 4). However, for Telone II (although not for Vorlex), disease ratings were significantly lower for all application rates when the trials were water-sealed after fumigation (Tables 4 and 5).

Disease ratings of roots were correlated positively with percent tare for 1985 ($r = 0.97$, $P = 0.0001$) and 1986 ($r = 1.0$). In that year, plots treated with metham-sodium and the low rate of chloropicrin (21.3 L/ha) had a significantly higher percent tare than plots treated with the other fumigants and were not different in that respect from the untreated controls (Table 3). Percent tare was not affected by postfumigation water treatment in the 1986 trials (Table 5).

Effect of fumigation on yield. All in-bed fumigation treatments significantly increased yield compared to the untreated controls. Treatments containing dichloropropene provided the greatest increase. Sugar yields were 42–106% greater than in the untreated controls in 1985 (Table 3) and 101–277% greater in 1986 (Table 4). In 1985, both metham-sodium and the low rate of chloropicrin (21.3 L/ha) provided poor control of rhizomania but increased beet yields by about 40% and sugar yields by 42–44% (Table 3).

Although the higher rates of Telone II and Pichlor 60 (58.6 and 66.5 L/ha, respectively) were associated with lower disease ratings than the lower rates (29.3 and 32.7 L/ha, respectively), there was no difference in beet yield for either fumigant or in sugar yield for Telone II (the higher rate of Pichlor 60 did raise sugar yield significantly). The high (45.2 L/ha) and low (21.3 L/ha) chloropicrin treatments did not differ significantly in beet or sugar yield, even though the low rate gave poorer disease control than the high rate (disease ratings of 2.2 and 0.7, respectively).

Vorlex and Vorlex 201 had similar effects on yield, as did other treatments containing dichloropropene that had low disease ratings. The higher rates of Telone II and Vorlex applied in 1986 resulted in higher yields than the lower rates tested (Table 4). Beet and sugar yields at the low rate of Telone II (29.5 L/ha) were significantly greater when the soil was water-sealed after fumigation (Tables 4 and 5). Although this effect was not observed at the higher application rates of Telone II, it was noted for all rates of Vorlex. In 1987, as in the previous two years, Telone II at 58.6 L/ha significantly boosted sugar yield over untreated controls (4,075 kg/ha, a 242% increase) (Table 4). The highest yield of all fumigants evaluated was obtained with methyl bromide in 1987 (7,005 kg/ha, a 488% increase over the control) (Table 4).

Tissue analysis. Beets from fumigated plots had significantly higher purity ratings (total solids/sugar) and lower percentages of nonsucrose soluble solids (NSSS) (percent NSSS = percent root purity minus percent root sucrose) than those from untreated plots. For the 1985 trials, raw juice apparent purity (RJAP) (RJAP = percent sucrose in root extract divided by percent root purity) did not differ significantly among fumigants (0.825–0.839) but was significantly greater than in the untreated control (0.799). Similar results were observed in 1986 except that the RJAP for the high Telone II rate (0.859 for 58.6 L/ha) was significantly greater than for the low rates of Telone II and Vorlex (0.84 for both 29.5 and 43.9 L/ha, respectively). In 1987, RJAP for the methyl bromide and Telone II treatments (0.823 and 0.821, respectively) was significantly higher than for the untreated control (0.735).

For both trial years 1985 and 1986, the percent NSSS was significantly greater for untreated controls (2.85 and 2.91, respectively) than for roots from fumigation treatments (2.34–2.59 and 2.16–2.41, respectively). In 1986 the percent NSSS for the high Telone II rate (2.16 for 58.6 L/ha) was significantly lower than for the other fumigation treatments. Sealing the soil with water after fumigation had no effect on RJAP or percent NSSS.

In 1985, soil fumigation did not significantly alter concentrations of root sodium (822–1,109 ppm), potassium (1,855–2,184 ppm), or amino nitrates (101–144 ppm) compared to levels in untreated controls. Likewise, there were no significant differences among treatments (including the control) in crown sodium (973–1,392 ppm) or potassium (2,686–2,989 ppm). Although plants grown at the high rates of Pichlor 60 and Vorlex (66.5 and 132.7 L/ha, respectively) had significantly higher concentrations of amino nitrates (352

Table 2. Time of infection of sugar beet roots with beet necrotic yellow vein virus (BNYVV) in 1985 field trials[a]

Treatment	Rate[b] (L/ha)	BNYVV infection at the following number of weeks after planting[c]					
		3	5	7	9	11	21
None	...	4	4	4	4	4	4
Metham-sodium	71.7	4	4	4	4	4	4
Telone II	29.3	0	0	0	2	3	4
	58.6	0	0	0	0	0	0
Vorlex	132.7	0	0	0	0	0	0
Vorlex 201	146.1	0	0	0	0	0	1
Pichlor 60	37.2	0	0	0	0	4	4
	66.5	0	0	0	0	0	3
Chloropicrin	21.3	4	2	2	3	4	4
	45.2	0	1	1	3	3	4

[a] Plants were grown in soil naturally infested with *Polymyxa betae* contaminated with BNYVV.
[b] Amount of product applied (see Table 1 for amounts of active ingredients).
[c] Number of replicates out of four that contained BNYVV-infected plants, as determined by enzyme-linked immunosorbent assay of root tissue extracts.

Table 3. Effect of soil fumigation on disease rating, tare, and yield of 21-wk-old sugar beet plants grown in field soil with a history of rhizomania in 1985 trials[x]

Treatment	Rate (L/ha)	Disease rating[y]	Tare[z] (%)	Yield	
				Beets (t/ha)	Sugar (kg/ha)
None	...	3.1 e	14.7 a	24.0 e	2,777 e
Metham-sodium	71.7	2.4 e	10.6 a	33.0 d	3,947 d
Telone II	29.3	0.5 cd	5.1 b	40.2 bc	5,069 ab
	58.6	0.0 a	3.9 b	41.9 abc	4,953 abc
Vorlex	132.7	0.0 a	4.7 b	42.3 abc	5,244 ab
Vorlex 201	146.1	0.2 bc	5.4 b	43.9 ab	4,887 abcd
Pichlor 60	37.2	0.7 d	6.1 b	41.0 abc	4,714 bcd
	66.5	0.0 ab	4.2 b	46.6 a	5,722 a
Chloropicrin	21.3	2.2 e	10.7 a	33.8 d	3,996 cd
	45.2	0.7 d	5.6 b	37.8 cd	4,594 bcd

[x] Values in each column followed by the same letter do not differ ($P = 0.05$) according to Duncan's multiple range test.
[y] Disease was rated visually on a scale from 0 (healthy) to 6 (dead).
[z] Percent tare = root field weight minus clean weight divided by root field weight and multiplied by 100.

and 325 ppm, respectively) than all other treatments (248–299 ppm), no differences were observed between other fumigants and the untreated control.

As in 1985, treatments in the 1986 trial did not differ significantly in concentration of root sodium (857–1,363 ppm); however, untreated controls had significantly higher concentrations of root potassium (1,973 ppm) than did fumigation treatments (1,711–1,826 ppm; no differences among fumigants). Root amino nitrate concentrations ranged from 78.5 to 148 ppm; the concentration in the untreated control (78.5 ppm) was significantly lower than at the middle rate (43.9 L/ha) of Telone II (114 ppm) and the higher rates (87.8 and 132.5 L/ha) of Vorlex (111 and 148 ppm, respectively). Crown sodium was significantly lower in untreated controls than with all fumigants, and water treatment made a difference in this respect. When the soil was not sealed with water after fumigation, the crown sodium concentration in roots from fumigation treatments ranged from 1,264 to 1,501 ppm, compared to 892 ppm in untreated controls. When the soil was sealed, crown sodium was 1,111 ppm for untreated controls and ranged from 1,348 to 1,477 ppm in roots from fumigation treatments. No differences in crown potassium were observed among treatments (2,433–2,742 ppm). Concentrations of crown amino nitrates ranged from 211 to 404 ppm, and the untreated control was significantly lower (211 ppm) than all fumigants. Although amino nitrates for the low Vorlex rate (43.9 L/ha) were significantly lower than for the high rate (132.5 L/ha) (292 and 404 ppm, respectively), there were no significant differences among the other fumigants. Postfumigation sealing of the soil with water had no effect on concentrations of the ions assayed, with the exception of crown sodium.

Table 4. Effect of soil fumigation and water sealing on time of infection, disease rating, tare, and yield of 22-wk-old sugar beet plants grown in field soil naturally infested with *Polymyxa betae* contaminated with beet necrotic yellow vein virus

Treatment	Rate (L/ha)	Virus infection[v]	Disease rating	Tare[w] (%)	Yield: Beets (t/ha)	Yield: Sugar (kg/ha)
1986, soil water-sealed after fumigation						
Control	...	4	4.1	9.4	14.3	1,659
Telone II	29.5	4	0.4	5.8	36.6	4,684
	43.9	1	0.1	5.0	44.2	5,845
	58.6	1	0.1	2.9	46.0	5,947
			$b = -0.009$[x] ($P = 0.047$)	$b = -0.009$ ($P = 0.24$)	$b = 0.32$[y] ($P = 0.0002$)	$b = 43.29$[y] ($P = 0.0001$)
Vorlex	43.9	4	1.8	5.7	32.7	4,147
	87.8	0	0.1	3.0	40.4	5,121
	132.5	0	0.1	4.2	47.3	6,252
			$b = -0.012$[y] ($P = 0.000$)	$b = -0.004$ ($P = 0.095$)	$b = 0.165$ ($P = 0.000$)	$b = 23.75$ ($P = 0.000$)
1986, soil not water-sealed after fumigation						
Control	...	4	4.1	12.7	18.6	1,981
Telone II	29.5	4	1.3	4.0	33.4	3,975
	43.9	0	0.5	4.1	41.7	4,876
	58.6	1	0.2	2.8	42.5	5,353
			$b = -0.025$ ($P = 0.000$)	$b = -0.026$ ($P = 0.002$)	$b = 0.31$[y] ($P = 0.0003$)	$b = 47.33$[y] ($P = 0.00002$)
Vorlex	43.9	3	2.1	4.1	35.7	4,084
	87.8	0	0.3	3.4	38.3	5,020
	132.5	1	0.2	3.0	40.2	5,081
			$b = -0.011$[y] ($P = 0.000$)	$b = -0.003$ ($P = 0.199$)	$b = 0.052$ ($P = 0.05$)	$b = 11.22$ ($P = 0.001$)
1987[z]						
Control	...	4	3.6 a	20.1 a	16.4 a	1,192 a
Telone II	58.6	0	0.1 b	9.2 b	38.3 b	4,075 b
Methyl bromide	254.5	0	0.0 c	5.8 b	62.1 c	7,005 c

[v] Number of replicates out of four in which the virus was observed 4 wk after planting for 1986 and 9 wk after planting for 1987, as determined by enzyme-linked immunosorbent assay of root tissue extract using antisera specific for the virus.

[w] Percent tare = root field weight minus clean weight divided by root field weight and multiplied by 100.

[x] b is the regression estimate of the slope of the line relating the measurement and the treatment rate.

[y] Quadratic contrast across continuous concentrations of the fumigants was significant, indicating that the linear model would be poor for predictive purposes but that significance of the linear slope can still be interpreted in terms of overall increase or decrease.

[z] Values in each column followed by the same letter do not differ ($P = 0.05$) according to Duncan's multiple range test.

DISCUSSION

Soil fumigants applied as preplant, in-bed treatments significantly increased beet and sugar yields compared to untreated controls. Excluding methyl bromide, the most effective control of rhizomania was obtained with compounds containing dichloropropene. Comparing the total amount of fumigants applied, Telone II (which is 92% dichloropropene) was the most effective at any given rate. Vorlex and Vorlex 201 applied at rates containing similar amounts of dichloropropene had similar effects on disease rating and yield (Tables 3 and 4).

The results of the 1986 trial indicate that sealing the soil with water after fumigation does not appear to be necessary to control rhizomania with these products in a silty loam soil (Table 4); however, yields were significantly greater with the low rate of Telone II (29.5 L/ha) and all rates of Vorlex when this procedure was followed (Table 5).

Besides Telone II, Vorlex, Vorlex 201, and Pichlor 60 were the other products evaluated that contained dichloropropene and were effective in controlling rhizomania. The other active compounds present in these products were methylisothiocyanate and chloropicrin (Table 1). When applied to the soil, metham-sodium degrades to methylisothiocyanate, which is efficacious against many soilborne pathogens. However, in view of the ineffectiveness of metham-sodium in reducing root disease (Table 3), the methylisothiocyanate component of

Table 5. Interaction of post-fumigation water treatments with effects of fumigant application on disease control, tare, and yield in 1986 trials

Dependent variable	Linear contrast	F value	$P > F$
Disease rating	Water × Telone II	7.37	0.010
	Water × Vorlex	0.51	0.479
Tare (%)	Water × Telone II	2.23	0.144
	Water × Vorlex	0.08	0.783
Beet yield	Water × Telone II	0.01	0.920
	Water × Vorlex	9.82	0.003
	Water × Telone II (29.5 L/ha) versus control	5.48	0.025
Sugar yield	Water × Telone II	0.09	0.770
	Water × Vorlex	8.04	0.008
	Water × Telone II (29.5 L/ha) versus control	6.98	0.012

Vorlex and Vorlex 201 does not appear to contribute much to the control of rhizomania. Similarly, the low efficacy of chloropicrin when used individually indicates that this compound contributes little to rhizomania control by Vorlex 201 and Pichlor 60. Therefore, dichloropropene appears to be the active component in these fumigants responsible for controlling *P. betae*. This conclusion is consistent with the results of Alghisi and D'Ambra (1) and Hess and Schlosser (7). Because the use of both metham-sodium and chloropicrin significantly increased yields compared to untreated controls but did not affect rhizomania (Table 3), these products may have controlled other root pathogens involved in yield reduction. Control of other root pathogens may also have contributed to the greater yields obtained with methyl bromide compared to Telone II (Table 4).

The extent of disease control and the effect on yield were positively correlated with how long the roots were protected from infection. Treatments in which virus was not detected in significant amounts until 9–11 wk after planting (Telone II and Pichlor 60 at 29.3 and 37.2 L/ha, respectively) had sugar yields similar to those obtained with treatments that remained virus-free throughout the trials (Telone II and Vorlex at 58.6 and 132.7 L/ha, respectively) (Table 3). The fact that roots from the former treatments had low but significantly higher disease ratings than roots from the latter treatments suggests that protection from infection in the early stages of plant growth is critical in preventing yield reductions. This association between time of infection and effect on yield is in general agreement with trials conducted with microplots infested at different times with virus-contaminated *P. betae* (F. N. Martin, E. D. Whitney, and J. E. Duffus, *unpublished*) and field trials in which soil fumigated with methyl bromide was naturally reinfested with virus-contaminated *P. betae* (E. D. Whitney, *unpublished*).

In addition to greater yield, roots with low disease ratings have higher purity and lower percent tare and percent NSSS (e.g., NH_4^+, Na^+, and K^+) than roots with high disease ratings. This higher quality is important in the processing of beets for sugar extraction because increased NSSS and percent tare decrease the percentage of extractable sugar. Reductions in percent tare also reflect reductions in nonprocessible material, mainly soil, which must be disposed of at the processing site.

Hess and Schlosser (7) controlled rhizomania with dichloropropene applied as a broadcast treatment at a rate (150 L/ha) that may not be economically feasible for growers in California. The results of our trials demonstrate that broadcast treatment of fields is not necessary for effective control, because in-bed applications before seeding significantly reduce disease severity and increase yield. Such treatments at the lower rates of fumigant application may be economically feasible for commercial growers. In 1988, the cost of Telone II was $2.50/L, and an application rate of 43.9 L/ha would have cost $110/ha. Although application rates may vary depending on soil type and severity of soil infestation, this rate increased sugar yield for 21-wk-old plants 146–252% in our trials.

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